KCE
ThermoFluidProperties

Property Library for Hydrogen

FluidEXL *Graphics* with LibH2 for Excel®

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Software for the Calculation of the Properties of Hydrogen Including DLL and Add-In for Excel®

FluidEXL*Graphics* LibH2

Contents

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0 Package Contents

0.1 Zip files for 64-bit Office®

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

CD_FluidEXL_Graphics_Eng_LibH2_x64.zip

including the following folders an files:

\FLUFT\

\Formulation97\

FluidEXL_Graphics_LibH2_Docu_Eng.pdf

FluidEXL_Graphics_Eng.xla

LC.dll

LibH2.dll

LibH2.chm.

0.2 Zip files for 32-bit Office®

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

CD_FluidEXL_Graphics_Eng_LibH2.zip

including the following folders and files:

\FLUFT\

\Formulation97\

FluidEXL_Graphics_LibH2_Docu_Eng.pdf

FluidEXL_Graphics_Eng.xla

LC.dll

LibH2.dll

LibH2.chm.

1. Property Functions

Functional Dependence	Function Name	Call from Fortran program	Property or Function	Unit of the result
a = f(p,t,x,NP)	a_ptx_H2	APTXH2(P,T,X,NP)	Thermal diffusivity	m^2/s
c_p = f(p,t,x,NP)	cp_ptx_H2	CPPTXH2(P,T,X,NP)	Specific isobaric heat capacity	kJ/(kg K)
c_v = f(p,t,x,NP)	cp_ptx_H2	CVPTXH2(P,T,X,NP)	Specific isochoric heat capacity	kJ/(kg K)
η = f(p,t,x,NP)	eta_ptx_H2	ETAPTXH2(P,T,X,NP)	Dynamic viscosity	Pa s
h = f(p,t,x,NP)	h_ptx_H2	HPTXH2(P,T,X,NP)	Specific enthalpy	kJ/kg
κ = f(p,t,x,NP)	kappa_ptx_H2	KAPPTXH2(P,T,X,NP)	Isentropic exponent	-
λ = f(p,t,x,NP)	lambda_ptx_H2	LAMPTXH2(P,T,X,NP)	Thermal conductivity	W/(m K)
ν = f(p,t,x,NP)	ny_ptx_H2	NYPTXH2(P,T,X,NP)	Kinematic viscosity	m^2/s
p_{mel} = f(t,NP)	pmel_t_H2	PMELTH2(T,NP)	Melting pressure from temperature	bar
p_s = f(t,NP)	ps_t_H2	PSTH2(T,NP)	Vapor pressure from temperature	bar
Pr = f(p,t,x,NP)	Pr_ptx_H2	PRPTXH2(P,T,X,NP)	*Prandtl*-Number	-
ρ = f(p,t,x,NP)	rho_ptx_H2	RHOPTXH2(P,T,X,NP)	Density	kg/m^3
s = f(p,t,x,NP)	s_ptx_H2	SPTXH2(P,T,X,NP)	Specific entropy	kJ/(kg K)
t = f(p,h,NP)	t_ph_H2	TPHH2(P,H,NP)	Backward function: Temperature from pressure and enthalpy	°C
t = f(p,s,NP)	t_ps_H2	TPSH2(P,S,NP)	Backward function: Temperature from pressure and entropy	°C
t_{mel} = f(p,NP)	tmel_p_H2	TMELPH2(P,NP)	Melting temperature from pressure	°C
t_s = f(p,NP)	ts_p_H2	TSPH2(P,NP)	Boiling temperature from pressure	°C
u = f(p,t,x,NP)	u_ptx_H2	UPTXH2(P,T,X,NP)	Internal energy	kJ/kg
v = f(p,t,x,NP)	v_ptx_H2	VPTXH2(P,T,X,NP)	Specific volume	m^3/kg
w = f(p,t,x,NP)	w_ptx_H2	WPTXH2(P,T,X,NP)	Isentropic speed of sound	m/s^2
x = f(p,h,NP)	x_ph_H2	XPHH2(P,H,NP)	Backward function: Vapor fraction from pressure and enthalpy	kg/kg
x = f(p,s,NP)	x_ps_H2	XPSH2(P,S,NP)	Backward function: Vapor fraction from pressure and entropy	kg/kg
z = f(p,t,x,NP)	z_ptx_H2	ZPTXH2(P,T,X,NP)	Compression factor	-

Units:

t in °C
p in bar
x in (kg of saturated steam)/(kg wet steam)
NP is a non-dimensional parameter

Hints for the parameter NP

Hydrogen can be calculated as H_2-Normal and H_2-Para. The form is specified by the parameter NP.

The parameter NP can take the following values: NP = 1, for H_2-Normal,

NP = 0, for H_2-Para.

Details on the vapor fraction *x*

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 two phase region (wet steam), either the value 0 or 1 has to be entered for *x* (x = 0 for boiling liquid, x = 1 for saturated steam). Here the backward functions will result in x = 0 or x = 1.

If the state point to be calculated is located in the two phase region, it is adequate to enter either the given value for *t* <u>and</u> p = –1000, or the given value for *p* <u>and</u> t = –1000, plus the value for *x* between 0 and 1. When calculating wet steam and *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in –1000.

Wet steam region:

H_2-Para (NP = 0): Temperature range from t_t = - 259.35 °C to t_c = - 240.212 °C
Pressure range from p_t = 0.0703991859 bar to p_c = 12.837878 bar

H_2-Normal (NP = 1): Temperature range from t_t = - 259,193 °C to t_c = - 240.212 °C
Pressure range from p_t = 0.0770478607 bar to p_c = 12.837878 bar

Range of validity

Temperature range:

H_2-Para (NP = 0):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 726.85 °C at $p \geq p_t$ = 0.0703991859 bar,

with ρ_{max} = 44.0 mol/l (v_{min} = 0.0112737843 m^3/kg)

from t_{trip} = -259.35 °C to 726.85 °C at $p \leq p_t$ = 0.0703991859 bar

H_2-Normal (NP = 1):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 726.85 °C at $p \geq p_t$ = 0.0770478607 bar,

with ρ_{max} = 38.148 mol/l (v_{min} = 0.0130032114 m^3/kg)

from t_{trip} = - 259.193 °C to 726.85 °C at $p \leq p_t$ = 0.0770478607 bar

Pressure range: from 0.001 bar to 1210 bar

Specifications for calculating the state variables of hydrogen

The calculation of the state variables of H_2-Normal und H_2-Para is based upon the following approximations:

- The specific volume $v = f(p,t)$ for H_2-Normal is also calculated according to the equation of H_2-Para from Younglove [22].
- The equation of vapor pressure from Lemmon [24] for H_2-Para is also used for H_2-Normal.
- The same critical point is taken for H_2-Normal and H_2-Para: p_c = 12.837878 bar, t_c = - 240.212 °C.
- An equation of the melting pressure $p_{mel} = f(t)$ for H_2-Normal does not exist. The calculable range of state of H_2-Normal is determined by the maximum molar density ρ_{max} = 38.148 mol/l. This corresponds to a minimum specific volume of v_{min} = 0.01300321 m^3/kg.
- The range of validity of the equation of state of H_2-Para is confined by the maximum molar density ρ_{max} = 44.0 mol/l. This corresponds to a minimum specific volume of v_{min} = 0.0112737843 m^3/kg.

The calculation of the state variables H_2-Normal and H_2-Para varies only in the different equations of the isobaric heat capacity of the ideal gas.

Reference state

h = 0 and s = 0

at p = 1.01325 bar

and t = - 252.8731 °C

Hint!

If the calculation results in –1000, the values entered represent a state point beyond the range of validity of LibH2. For further information on each function and its range of validity see Chapter 3. The same information may also be accessed via the online help pages.

2. Application of FluidEXL*Graphics* in Excel®

The FluidEXL*Graphics* Add-In has been developed to calculate thermodynamic properties in Excel® more conveniently. Within Excel®, it enables the direct call of functions relating to Water and Steam from the LibH2 property program library.

2.1 Installing FluidEXL*Graphics*

Complete the following steps for initial installation of FluidEXL*Graphics*.
Before you begin, it is best to uninstall any older version of FluidEXL*Graphics*.

The installation routine for 32-bit and 64-bit versions of Excel is similar. The following instructions are valid for both versions.
After you have downloaded and extracted the zip-file:

CD_FluidEXL_Graphics_LibH2_x64_Eng.zip (for 64 bit version)

or

CD_FluidEXL_Graphics_LibH2_Eng.zip" (for 32 bit version).

you will see the folder

\CD_FluidEXL_Graphics_LibH2_x64_Eng\ (for 64 bit version)

or

\CD_FluidEXL_Graphics_LibH2_Eng\ (for 32 bit version)

in your Windows Explorer, Total Commander etc.

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

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

\FLUFT\
\Formulation97\
FluidEXL_Graphics_Eng.xla
FluidEXL_Graphics_LibH2_Docu_Eng
LC.dll
LibH2.dll
LibH2.chm
Reg_.reg

Now, please copy the following folders and files

\FLUFT\
\Formulation97\
FluidEXL_Graphics_Eng.xla
LibH2.dll
LibH2.chm
LC.dll

into the folder

C:\Users\[your name]\AppData\Roaming\Microsoft\AddIns\,

where [your name] is your name in the Windows system.

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

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

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

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

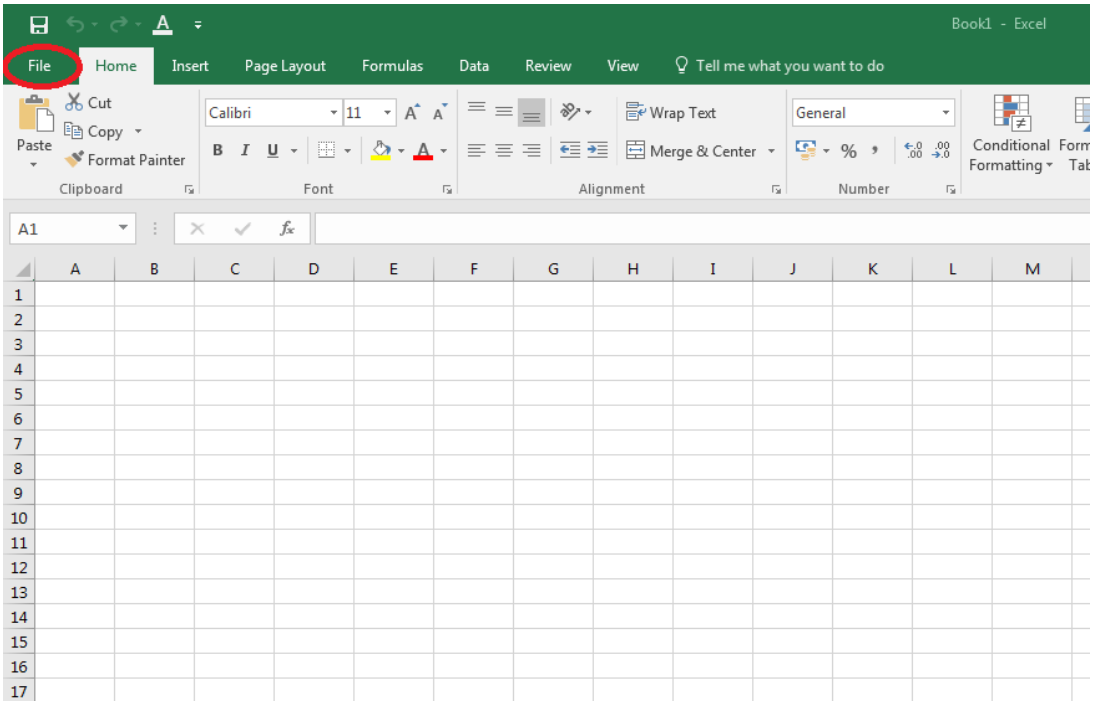


Figure 2.1: Registering FluidEXL*Graphics* as Add-In in Excel® 2016

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

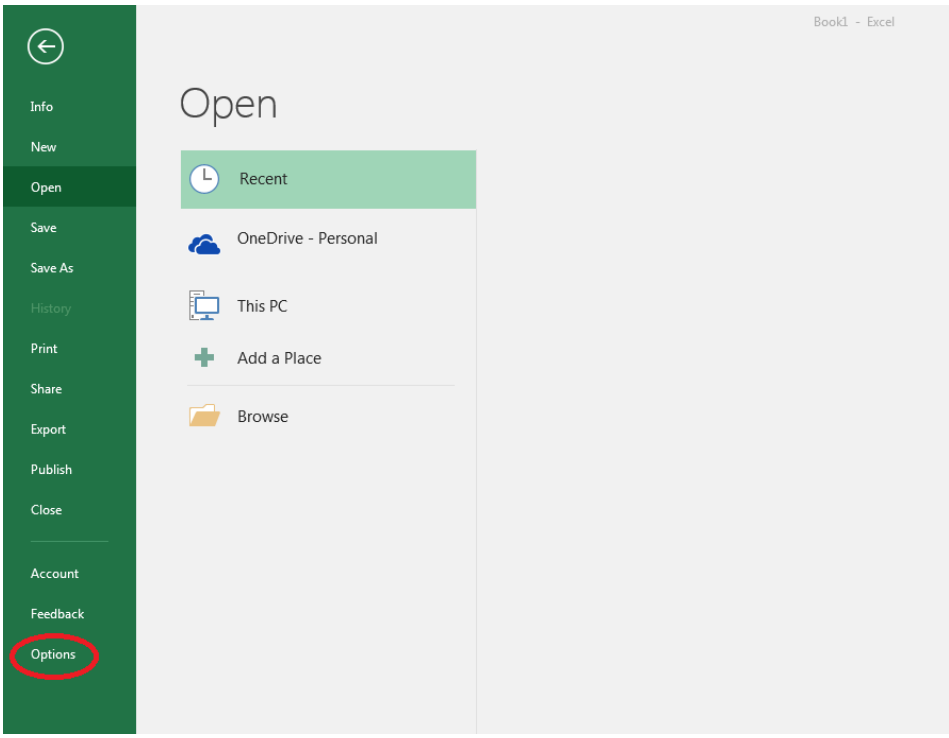


Figure 2.2: Registering FluidEXL*Graphics* as Add-In in Excel® 2016

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

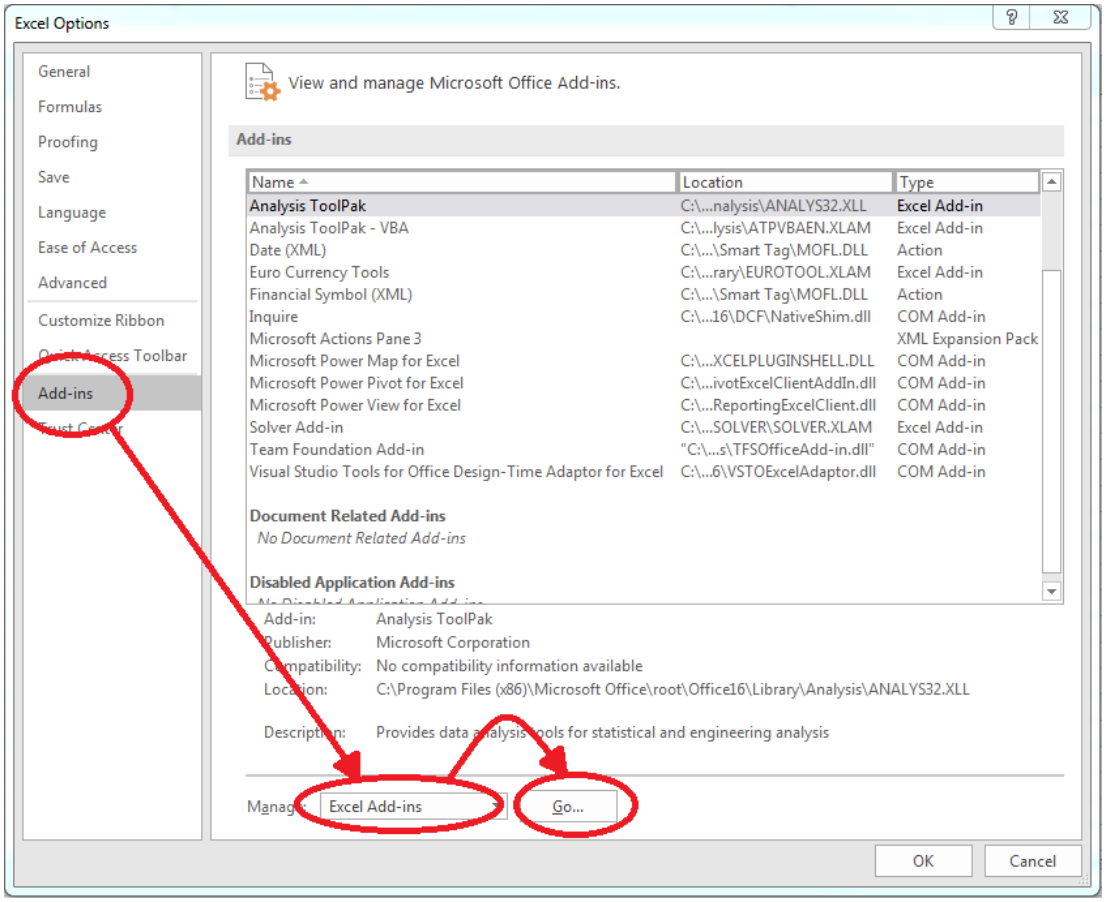


Figure 2.3: Dialog window "Excel Options"

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

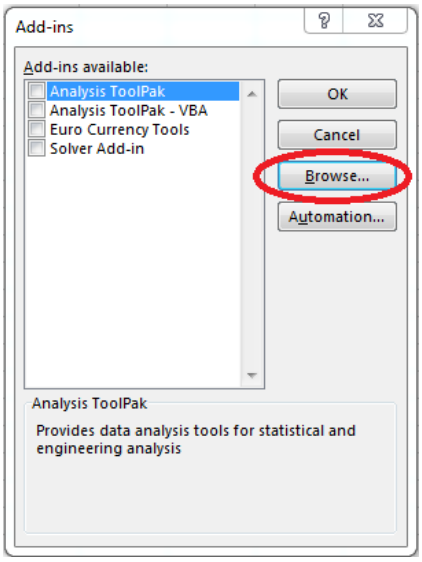


Figure 2.4: Dialog window "Add-ins"

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

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

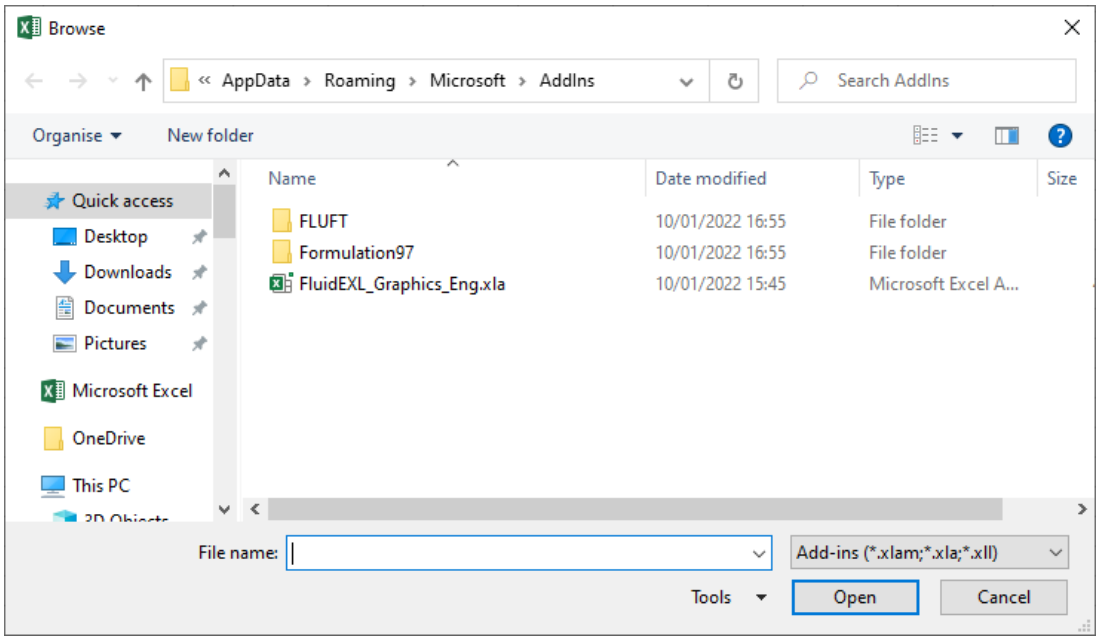


Figure 2.5: "Browse"-Window

  Please copy this path and paste it into your file manager.
  Now, please copy the following directories and files:

  \FLUFT\
  \Formulation97\
  LC.dll
  FluidEXL_Graphics_Eng.xla
  LibH2.dll
  LibH2.chm

  from the delivered CD-folder into this folder.

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

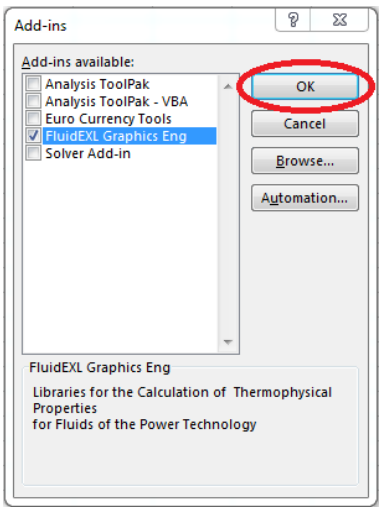


Figure 2.6: Dialog window "Add-Ins"

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

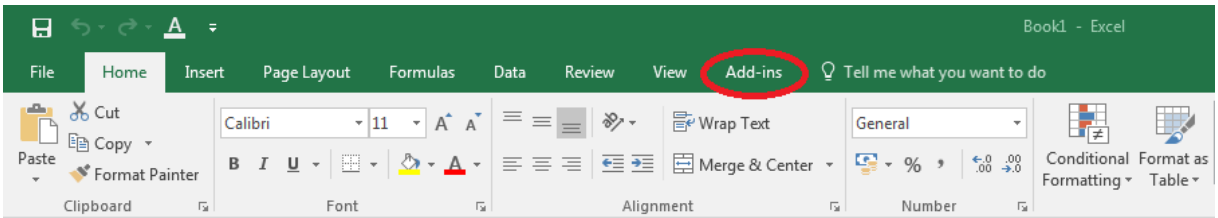


Figure 2.7: Menu item "Add-Ins"

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

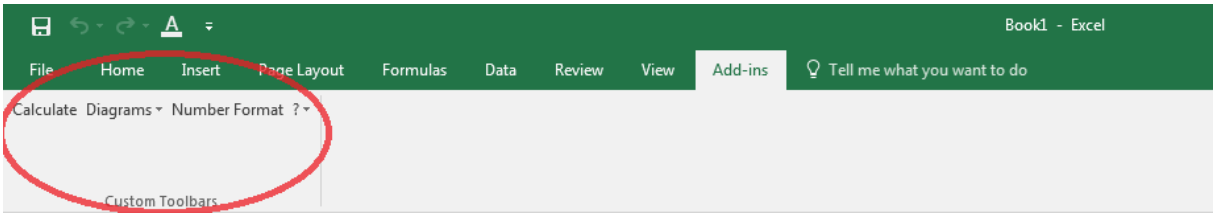


Figure 2.8: FluidEXL*Graphics* menu bar

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

An example calculation of "LibH2" DLL library property functions can be found in chapter 2.4.

2.3 Licensing the LibH2 Property LibH2rary

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

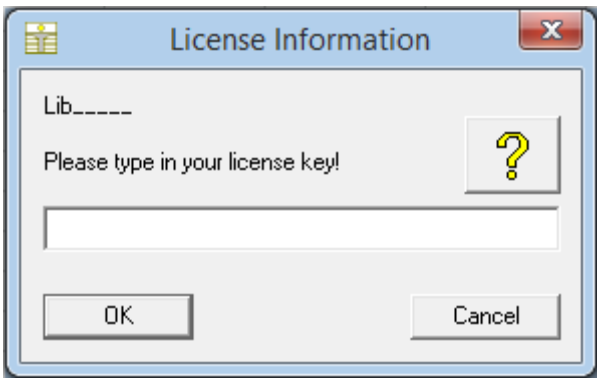


Figure 2.12: "License Information" window

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

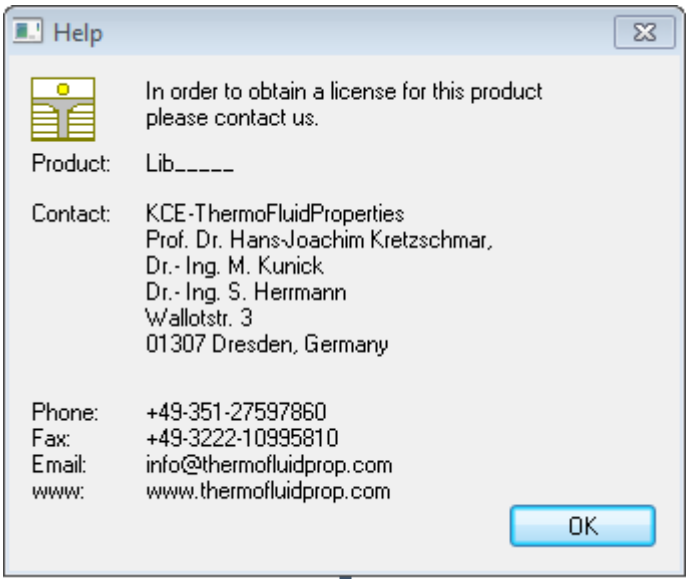


Figure 2.13: "Help" window

If you do not enter a valid license it is still possible to start Excel® by clicking "Cancel" twice. In this case, the LibH2 property library will display the result "–11111111" for every calculation. The "License Information" window will appear every time you start Excel® unless you uninstall FluidEXL^{Graphics} according to the description in section 2.6 of this User's Guide.
Should you not wish to license the LibH2 property library, you have to delete the files

LibH2.dll
LibH2.chm

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

C:\Program Files\FluidEXL_Graphics_Eng

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

Note:

The product name "LibH2_ _ _ _ _ in Figure 2.12 and 2.13 stands for the LibH2rary you are installing. In this case it is the LibH2 library.

2.4 Example calculation

Now we will calculate, step by step, the specific enthalpy *h* as a function of pressure *p*, temperature *t*, and vapor fraction *x*, using FluidEXL*Graphics*. Here we use a calculation in the single phase region as example to explain how the specific enthalpy *h* is calculated for H_2-Normal and H_2-Para. Please carry out the following steps:

- Enter the value for *p* in bar in a cell
  (Range of validity: p = 0.001 bar ... 1210 bar)
  ⇒ e. g.: Enter the value 10 for *p* into cell A3
- Enter the value for *t* in °C in a cell
  (Range of validity: $t = t_{mel}$ or t_{min} ... 126.85°C)
  ⇒ e. g.: Enter the value 25 for *t* into cell B3
- Enter the value for *x* in kg saturated steam/kg wet steam into a cell

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

  <u>Single-phase region</u>

  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.

  <u>Wet-steam region</u>

  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 –1000.

  Vapor pressure curve of H_2-Para:

  t_t = -259.35 °C ... t_c = 240.212 °C
  p_t = 0.0703991859 bar ... p_c = 12.837878 bar)

  Vapor pressure curve of H_2-Normal:

  t_t = -259,193 °C ... t_c = 240.212 °C
  p_t = 0.0770478607 bar ... p_c = 12.837878 bar)

  ⇒ e.g.: Enter the value -1 for *x* into cell C3
- Enter a value for NP into a cell

  Please note that you have to enter the value NP = 1 for H_2-Normal.
  In case H_2-Para is given, you have to enter the value NP = 0.

  ⇒ e.g.: Enter the value 1 for H_2-Normal into cell D2

  ⇒ e.g.: Enter the value 0 for H_2-Para into cell D3

The following steps have to be completed for the different forms of Hydrogen, H_2-Normal und H_2-Para. In order to obtain a better view, the results of the calculated enthalpy *h* in kJ/kg are being written next to the corresponding cells of the parameter NP.

- Click the cell into which the calculated enthalpy *h* in kJ/kg should be entered

⇒ e.g.: Click cell E3

- Click "Calculate" in the menu bar of FluidEXL*Graphics*
  The "Insert Function" menu, which is shown in Figure 2.9, pops up.

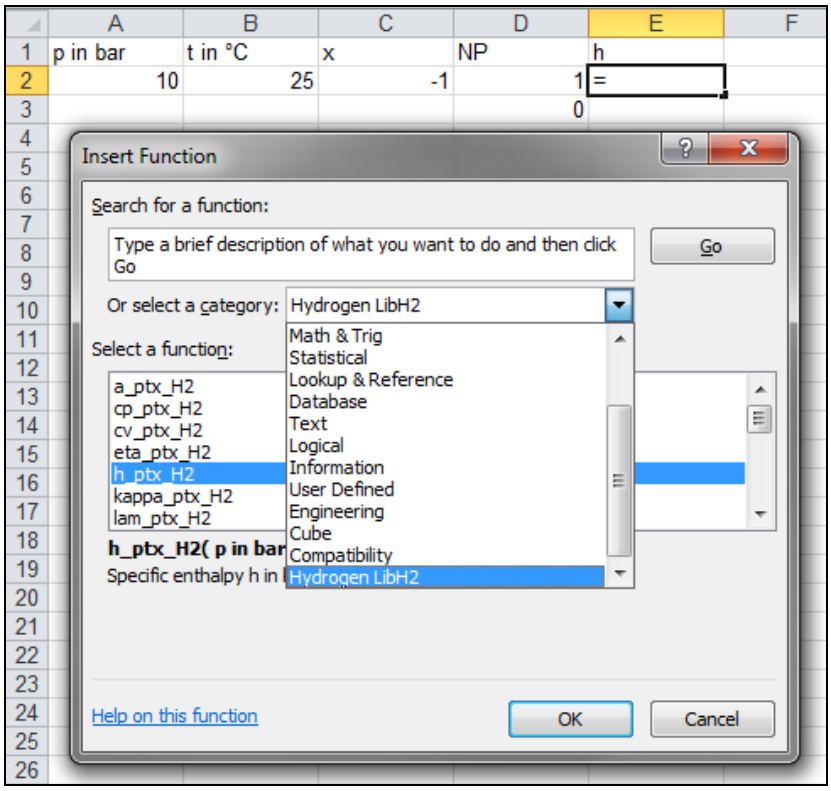


Figure 2.9: Choice of library and function name

- Search and click the "Hydrogen LibH2" library under "Or select a category:" in the upper part of the window.
- Search and click the "h_ptx_H2" function under "Select a function:" right below.
  Here it is possible to get more information on the range of validity, measuring units, and error responses etc. by clicking the "Help on this function" link.
- Click the "OK" button.
  The menu shown in Figure 2.10 will now appear.

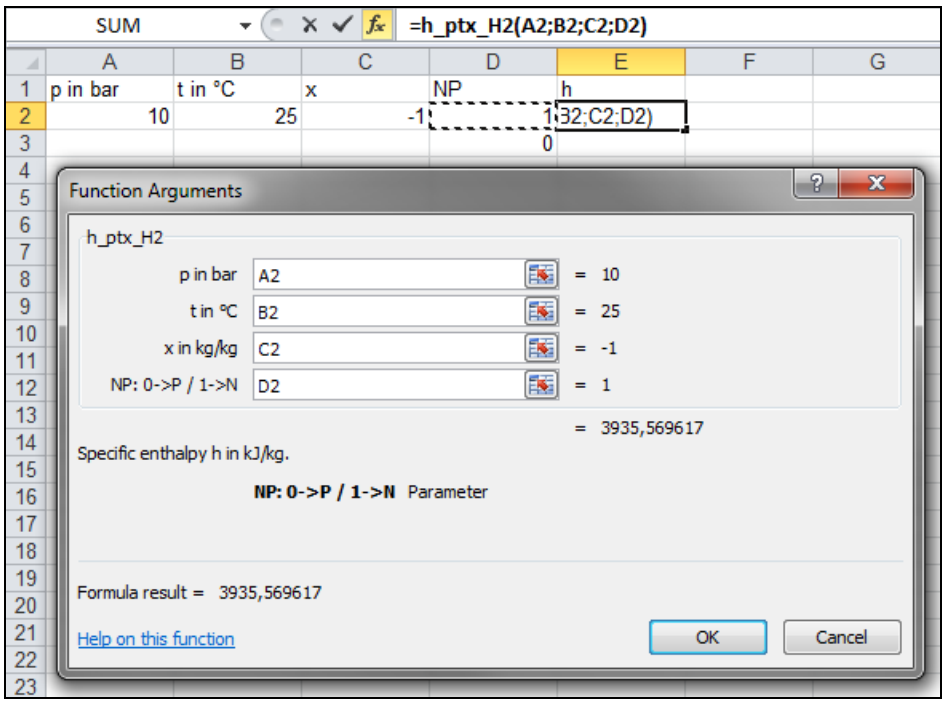


Figure 2.10: Enter the given values for the property calculation

- The cursor is now situated in the window next to "p in bar". You can now enter the value for *p* either by clicking the cell with the value for *p*, by entering the name of the cell with the value for *p*, or by entering the value for *p* directly.
- Situate the cursor next to "t in °C" and enter the value for *t* by clicking the cell with the value for *t*, by entering the name of the cell with the value for *t*, or by entering the value for *t* directly.
- Situate the cursor next to "x in kg/kg" and enter the value for *x* by clicking the cell with the value for *x*, by entering the name of the cell with the value for *x*, or by entering the value for *x* directly.
- Situate the cursor next to "NP" and enter the value for NP by clicking the cell with the value for NP, by entering the name of the cell with the value for NP, or by entering the value for NP directly.
- Click the "OK" button

The result of *h* in kJ/kg on the calculation of H_2-Normal now appears in the chosen cell.

⇒ The result of NP = 1 must be h = 3935.569617 kJ/kg.

Repeat calculation for NP = 0 (H_2-Para) by clicking cell D3. Complete the steps according to the calculation carried out before.

⇒ The result of NP = 0 must be h = 4431.970935 kJ/kg.

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

Hint:

If the calculation results in –1000, this indicates that the values entered are located outside the range of validity of LibH2. More detailed information on each function and its range of validity is available in Chapter 3.

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

Number Formats

When using FluidEXL*Graphics* you have the option of choosing special number formats in advance.
Changes can be made as follows:

- Click the cell or select and click on the cells you wish to format.
  (In empty cells the new format will be applied once a value has been entered.)
- Click "Number Format" in the FluidEXL*Graphics* menu bar.
- Select the desired number format in the dialog box which appears:

"STD – Standard":	Insignificant zeros behind the decimal point are not shown.
"FIX – Fixed Number of Digits":	All set decimal places are shown, including insignificant zeros.
"SCI – Scientific Format":	Numbers are always shown in the exponential form with the set number of decimal places.

- Set the "Number of decimal places" by entering the number into the appropriate window.
- Confirm this by clicking the "OK" button.

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

STD	1.23
FIX	1.230
SCI	1.230E+00

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

2.5 The FluidEXL*Graphics* Help System

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

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

- Click "Calculate" in the FluidEXL*Graphics* menu bar.
- Click on the “LibH2” library under "Or select a category:" in the "Insert Function" window which will appear.
- Click the "Help on this function" button in the lower left-hand edge of the "Insert Function" window.

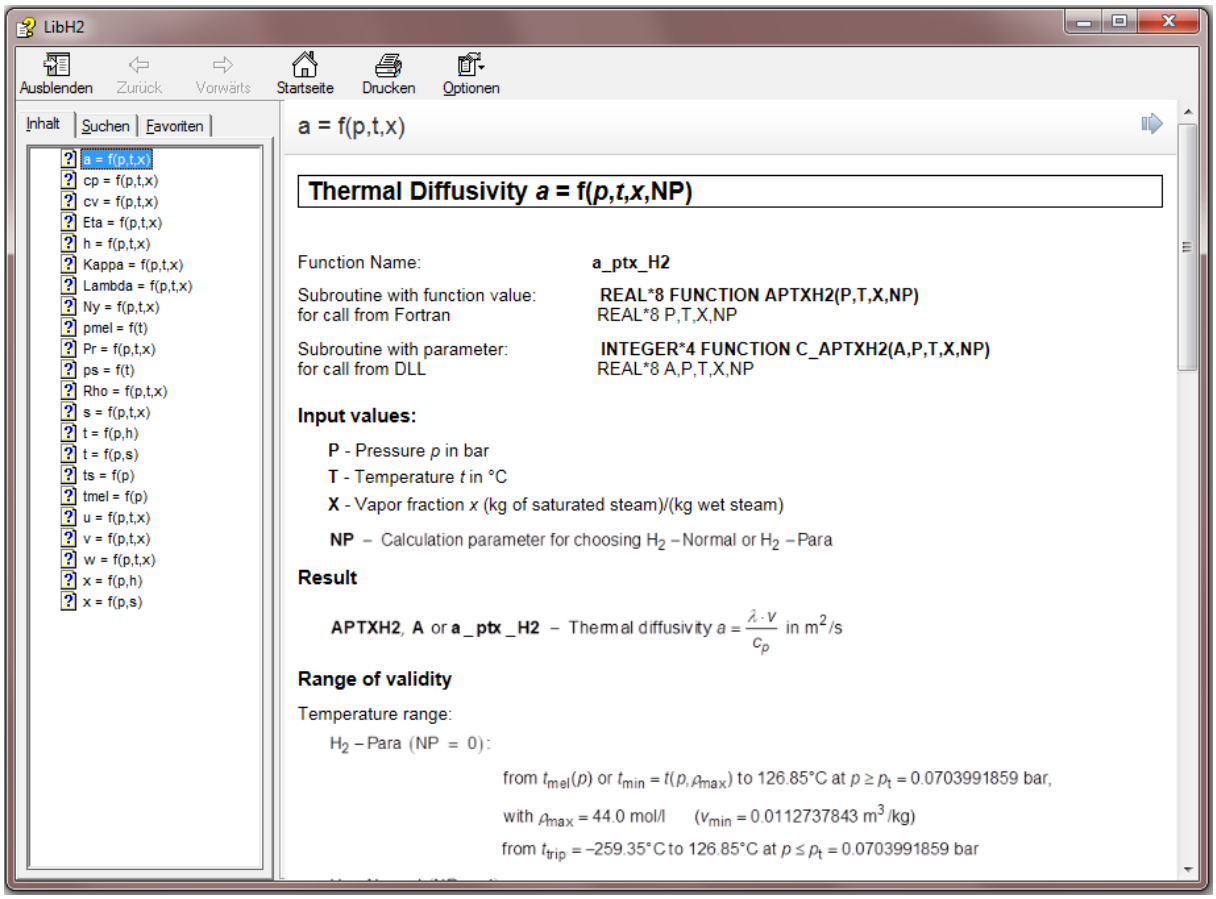


Figure 2.11: Help Window

If the LibH2.chm function help cannot be found, you will be redirected to a Microsoft® help website by your standard browser. In this case, the LibH2.chm file has to be copied into the folder of FluidEXL*Graphics*, in the standard case

C:\Program Files\FluidEXL_Graphics_Eng

to use the help system.

2.6 Removing FluidEXLGraphics

2.6.1 Removing LibH2 Library

Should you wish to remove <u>only</u> the LibH2 library, delete the files

LibH2.dll
LibH2.chm

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

C:\Program Files\FluidEXL_Graphics_Eng

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

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

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

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

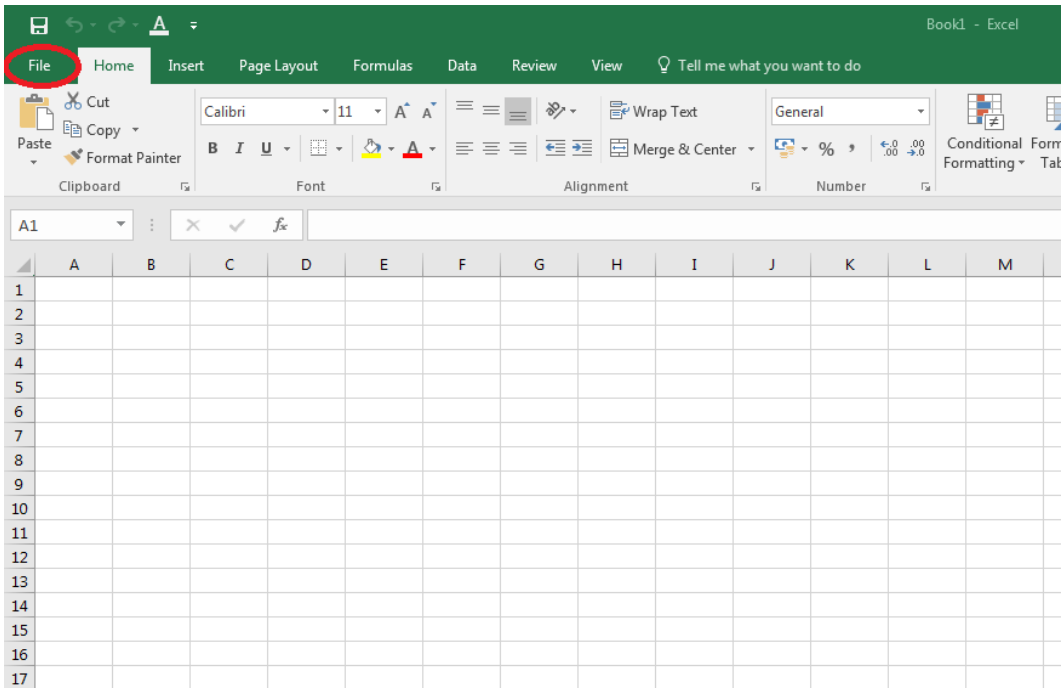


Figure 2.12: Unregistering FluidEXL*Graphics* as Add-In in Excel® 2016

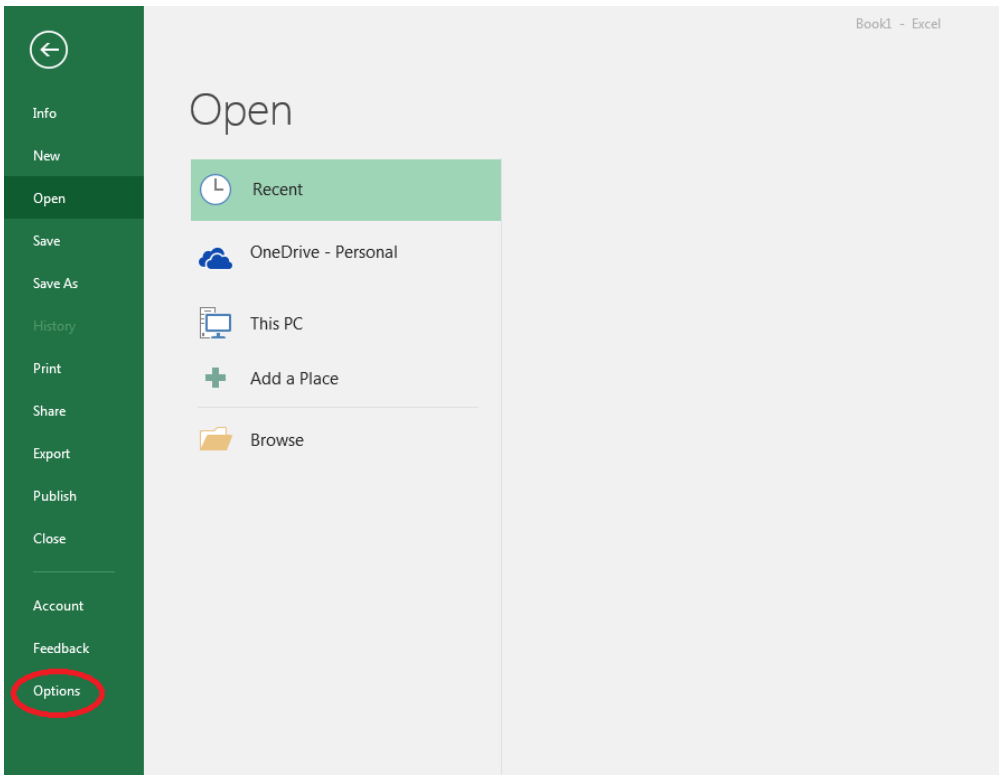


Figure 2.13 Unregistering FluidEXL*Graphics* as Add-In in Excel® 2016

- Click on "Add-Ins" in the next menu (Figure 2.14)

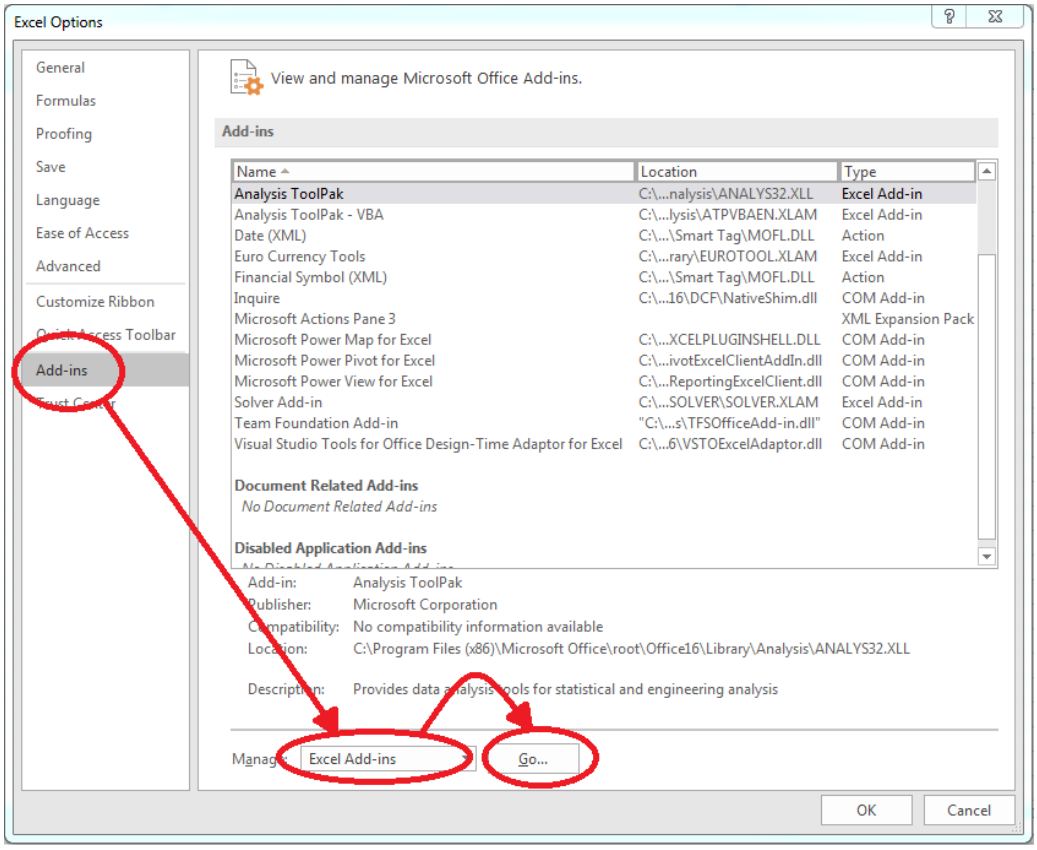


Figure 2.14: Dialog window "Add-Ins"

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

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

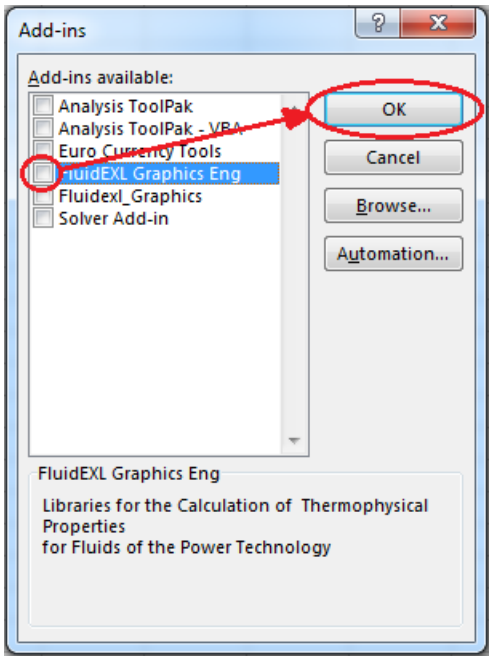


Figure 2.15: Dialog window "Add-Ins"

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

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

In the list box of the "Add or Remove Programs" window that appears, select
"FluidEXL Graphics Eng"
by clicking on it and then clicking the "Add/Remove…" button.

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

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

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

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

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

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

In order to do this, click "Tools" in the upper menu bar of Excel® and here "Add-Ins…". Untick the box on the left-hand side of
"FluidEXL Graphics Eng"
in the window that appears and click the "OK" button. The additional menu bar of FluidEXL*Graphics* disappears from the upper part of the Excel® window. Afterwards, we

recommend closing Excel®.

If the FluidEXL*Graphics* menu bar does not disappear, take the following steps:
Click "View" in the upper menu bar of Excel®, then "Toolbars" and then "Customize…" in the list box which appears.

"FluidEXL Graphics Eng"

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

Within the next step delete the files

LibH2.dll
LibH2.chm

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

C:\Program Files\FluidEXL_Graphics_Eng

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

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

"FluidEXL Graphics Eng"

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

Now FluidEXL*Graphics* has been removed.

3. Program Documentation

Thermal Diffusivity *a* = f(*p*,*t*,*x*,NP)

Function Name: **a_ptx_H2**

Subroutine with function value: **REAL*8 FUNCTION APTXH2(P,T,X,NP)**
for call from Fortran REAL*8 P,T,X,NP

Input values:

P - Pressure *p* in bar

T - Temperature *t* in °C

X - Vapor fraction *x* (kg of saturated steam)/(kg wet steam)

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

APTXH2, **A** or **a_ptx_H2** – Thermal diffusivity $a = \frac{\lambda \cdot v}{c_p}$ in m^2/s

Range of validity

Temperature range:

H_2 – Para (NP = 0):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 726.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal (NP = 1):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 726.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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. Here the backward functions will also result in x = -1.

If the state point to be calculated is located in the two phase region (wet steam), either the value 0 or 1 has to be entered for *x* (x = 0 for boiling liquid, x = 1 for saturated steam). Here the backward functions will result in x = 0 or x = 1.

If the state point to be calculated is located in the two phase region, it is adequate to enter either the given value for *t* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* between 0 and 1. When calculating wet steam and *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

H_2 – Normal (NP = 1): Temperature range from $t_t = -259.193$°C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H_2 – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **APTXH2 = -1000**, **A = -1000** or **a_ptx_H2 = -1000** for Input values:

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t =$ 0.0770478607 bar or

$t < t_{trip} = -259.193$ °C at $p < p_t =$ 0.0770478607 bar

$\rho_{max} =$ 38.148 mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0770478607 bar or
at p > 12.837878 bar or p < 0.0770478607 bar and
t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t =$ 0.0703991859 bar or

$t < t_{trip} = -259.35$ °C at $p < p_t =$ 0.0703991859 bar

$\rho_{max} =$ 44.0 mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0703991859 bar or
at p > 12.837878 bar or p < 0.0703991859 bar and
t > - 240.212 °C or t < - 259.35 °C

References: [22], [23]

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

Function Name: **cp_ptx_H2**

Subroutine with function value: **REAL*8 FUNCTION CPPTXH2(P,T,X,NP)**
for call from Fortran REAL*8 P,T,X,NP

Input values:

P - Pressure p in bar

T - Temperature t in °C

X - Vapor fraction x (kg of saturated steam)/(kg wet steam)

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

CPPTXH2, CP or cp_ptx_H2 – specific isobaric heat capacity c_p in kJ / (kg K)

Range of validity

Temperature range:

H_2 – Para (NP = 0):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 726.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal (NP = 1):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 726.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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. Here the backward functions will also result in x = -1.

If the state point to be calculated is located in the two phase region (wet steam), either the value 0 or 1 has to be entered for x (x = 0 for boiling liquid, x = 1 for saturated steam). Here the backward functions will result in x = 0 or x = 1.

If the state point to be calculated is located in the two phase region, it is adequate to enter either the given value for t <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

H_2 – Normal (NP = 1): Temperature range from $t_t = -259.193$°C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H_2 – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **CPPTXH2 = - 1000**, **CP = -1000** or **cp_ptx_H2 = - 1000** for Input values:

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0770478607$ bar or

$t < t_{trip} = -259.193$ °C at $p < p_t = 0.0770478607$ bar

$\rho_{max} = 38.148$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0770478607 bar or
at p > 12.837878 bar or p < 0.0770478607 bar and
t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0703991859$ bar or

$t < t_{trip} = -259.35$ °C at $p < p_t = 0.0703991859$ bar

$\rho_{max} = 44.0$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0703991859 bar or
at p > 12.837878 bar or p < 0.0703991859 bar and
t > - 240.212 °C or t < - 259.35 °C

References: [22]

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

Function Name: **cv_ptx_H2**

Subroutine with function value: **REAL*8 FUNCTION CVPTXH2(P,T,X,NP)**
for call from Fortran REAL*8 P,T,X,NP

Input values:

P - Pressure p in bar

T - Temperature t in °C

X - Vapor fraction x (kg of saturated steam)/(kg wet steam)

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

CVPTXH2, CV or cv_ptx_H2 – specific isochoric heat capacity c_v in kJ / (kg K)

Range of validity

Temperature range:

H_2 – Para (NP = 0):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal (NP = 1):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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. Here the backward functions will also result in x = -1.

If the state point to be calculated is located in the two phase region (wet steam), either the value 0 or 1 has to be entered for x (x = 0 for boiling liquid, x = 1 for saturated steam). Here the backward functions will result in x = 0 or x = 1.

If the state point to be calculated is located in the two phase region, it is adequate to enter either the given value for t <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

H_2 – Normal (NP = 1): Temperature range from $t_t = -259.193$°C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H_2 – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **CVPTXH2 = - 1000**, **CV = -1000** or **cv_ptx_H2 = - 1000** for Input values:

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0770478607$ bar or

$t < t_{trip} = -259.193$ °C at $p < p_t = 0.0770478607$ bar

$\rho_{max} = 38.148$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0770478607 bar or
at p > 12.837878 bar or p < 0.0770478607 bar and
t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0703991859$ bar or

$t < t_{trip} = -259.35$ °C at $p < p_t = 0.0703991859$ bar

$\rho_{max} = 44.0$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0703991859 bar or
at p > 12.837878 bar or p < 0.0703991859 bar and
t > - 240.212 °C or t < - 259.35 °C

References: [22]

Dynamic Viscosity η = f(p, t, x, NP)

Function Name: **eta_ptx_H2**

Subroutine with function value: **REAL*8 FUNCTION ETAPTXH2(P,T,X,NP)**
for call from Fortran REAL*8 P,T,X,NP

Input values:

P - Pressure p in bar

T - Temperature t in °C

X - Vapor fraction x (kg of saturated steam)/(kg wet steam)

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

ETAPTXH2, ETA or eta_ptx_H2 – dynamic viscosity η in Pa s

Range of validity

Temperature range:

H_2 – Para (NP = 0):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal (NP = 1):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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. Here the backward functions will also result in x = -1.

If the state point to be calculated is located in the two phase region (wet steam), either the value 0 or 1 has to be entered for x (x = 0 for boiling liquid, x = 1 for saturated steam). Here the backward functions will result in x = 0 or x = 1.

If the state point to be calculated is located in the two phase region, it is adequate to enter either the given value for t <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

H_2 – Normal (NP = 1): Temperature range from $t_t = -259.193$°C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H_2 – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **ETAPTXH2 = - 1000**, **ETA = -1000** or **eta_ptx_H2 = - 1000** for Input values:

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0770478607$ bar or

$t < t_{trip} = -259.193$ °C at $p < p_t = 0.0770478607$ bar

$\rho_{max} = 38.148$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0770478607 bar or
at p > 12.837878 bar or p < 0.0770478607 bar and
t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0703991859$ bar or

$t < t_{trip} = -259.35$ °C at $p < p_t = 0.0703991859$ bar

$\rho_{max} = 44.0$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0703991859 bar or
at p > 12.837878 bar or p < 0.0703991859 bar and
t > - 240.212 °C or t < - 259.35 °C

References: [22], [23]

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

Function Name: **h_ptx_H2**

Subroutine with function value: **REAL*8 FUNCTION HPTXH2(P,T,X,NP)**
for call from Fortran REAL*8 P,T,X,NP

Input values:

P - Pressure *p* in bar

T - Temperature *t* in °C

X - Vapor fraction *x* (kg of saturated steam)/(kg wet steam)

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

HPTXH2, **H** or **h_ptx_H2** - specific enthalpy *h* in kJ/kg

Range of validity

Temperature range:

H_2 – Para (NP = 0):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal (NP = 1):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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. Here the backward functions will also result in x = -1.

If the state point to be calculated is located in the two phase region (wet steam), either the value 0 or 1 has to be entered for *x* (x = 0 for boiling liquid, x = 1 for saturated steam). Here the backward functions will result in x = 0 or x = 1.

If the state point to be calculated is located in the two phase region, it is adequate to enter either the given value for *t* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* between 0 and 1. When calculating wet steam and *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

H_2 – Normal (NP = 1): Temperature range from $t_t = -259.193$°C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H_2 – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **HPTXH2 = -1000**, **H = -1000** or **h_ptx_H2 = -1000** for Input values:

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0770478607$ bar or

$t < t_{trip} = -259.193$ °C at $p < p_t = 0.0770478607$ bar

$\rho_{max} = 38.148$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0770478607 bar or
at p > 12.837878 bar or p < 0.0770478607 bar and
t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0703991859$ bar or

$t < t_{trip} = -259.35$ °C at $p < p_t = 0.0703991859$ bar

$\rho_{max} = 44.0$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0703991859 bar or
at p > 12.837878 bar or p < 0.0703991859 bar and
t > - 240.212 °C or t < - 259.35 °C

References: [22]

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

Function Name: **kappa_ptx_H2**

Subroutine with function value: **REAL*8 FUNCTION KAPPTXH2(P,T,X,NP)**
for call from Fortran REAL*8 P,T,X,NP

Input values:

P - Pressure p in bar

T - Temperature t in °C

X - Vapor fraction x (kg of saturated steam)/(kg wet steam)

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

KAPPTXH2, KAP or kappa_ptx_H2 - Isentropic exponent $\kappa = \frac{w^2}{p \cdot v}$

Range of validity

Temperature range:

H_2 – Para $(NP = 0)$:

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal $(NP = 1)$:

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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. Here the backward functions will also result in x = -1.

If the state point to be calculated is located in the two phase region (wet steam), either the value 0 or 1 has to be entered for x (x = 0 for boiling liquid, x = 1 for saturated steam). Here the backward functions will result in x = 0 or x = 1.

If the state point to be calculated is located in the two phase region, it is adequate to enter either the given value for t <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

H_2 – Normal $(NP = 1)$: Temperature range from $t_t = -259.193$°C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H_2 – Para $(NP = 0)$: Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **KAPPTXH2**, **KAP = - 1000** or **kappa_ptx_H2 = - 1000** for Input values:

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t =$ 0.0770478607 bar or

$t < t_{trip} = -259.193$ °C at $p < p_t =$ 0.0770478607 bar

$\rho_{max} =$ 38.148 mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0770478607 bar or
at p > 12.837878 bar or p < 0.0770478607 bar and
t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t =$ 0.0703991859 bar or

$t < t_{trip} = -259.35$ °C at $p < p_t =$ 0.0703991859 bar

$\rho_{max} =$ 44.0 mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0703991859 bar or
at p > 12.837878 bar or p < 0.0703991859 bar and
t > - 240.212 °C or t < - 259.35 °C

References: [22]

Thermal Conductivity λ = f(p, t, x, NP)

Function Name: **lambda_ptx_H2**

Subroutine with function value: **REAL*8 FUNCTION LAMPTH2(P,T,X,NP)**
for call from Fortran REAL*8 P,T,X,NP

Input values:

P - Pressure p in bar

T - Temperature t in °C

X - Vapor fraction x (kg of saturated steam)/(kg wet steam)

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

LAMPTXH2, **LAM or lambda_ptx_H2** - Thermal conductivity λ in W/m K

Range of validity

Temperature range:

H_2 – Para (NP = 0):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal (NP = 1):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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. Here the backward functions will also result in x = -1.

If the state point to be calculated is located in the two phase region (wet steam), either the value 0 or 1 has to be entered for x (x = 0 for boiling liquid, x = 1 for saturated steam). Here the backward functions will result in x = 0 or x = 1.

If the state point to be calculated is located in the two phase region, it is adequate to enter either the given value for t <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

H_2 – Normal (NP = 1): Temperature range from $t_t = -259.193$°C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H_2 – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **LAMPTXH2 = - 1000**, **LAM = -1000** or **lambda_ptx_H2 = - 1000** for Input values:

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0770478607$ bar or

$t < t_{trip} = -259.193$ °C at $p < p_t = 0.0770478607$ bar

$\rho_{max} = 38.148$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0770478607 bar or
at p > 12.837878 bar or p < 0.0770478607 bar and
t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0703991859$ bar or

$t < t_{trip} = -259.35$ °C at $p < p_t = 0.0703991859$ bar

$\rho_{max} = 44.0$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0703991859 bar or
at p > 12.837878 bar or p < 0.0703991859 bar and
t > - 240.212 °C or t < - 259.35 °C

References: [22], [23]

Kinematic Viscosity ν = f(p, t, x, NP)

Function Name: **ny_ptx_H2**

Subroutine with function value: **REAL*8 FUNCTION NYPTXH2(P,T,X,NP)**
for call from Fortran REAL*8 P,T,X,NP

Input values:

P - Pressure p in bar

T - Temperature t in °C

X - Vapor fraction x (kg of saturated steam)/(kg wet steam)

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

NYPTXH2, NY or ny_ptx_H2 - Kinematic viscosity $\nu = \eta \cdot v$ in m^2/s

Range of validity

Temperature range:

H_2 – Para (NP = 0):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal (NP = 1):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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. Here the backward functions will also result in x = -1.

If the state point to be calculated is located in the two phase region (wet steam), either the value 0 or 1 has to be entered for x (x = 0 for boiling liquid, x = 1 for saturated steam). Here the backward functions will result in x = 0 or x = 1.

If the state point to be calculated is located in the two phase region, it is adequate to enter either the given value for t <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

H_2 – Normal (NP = 1): Temperature range from $t_t = -259.193$°C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H_2 – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **NYPTXH2 = - 1000**, **NY = -1000** or **ny_ptx_H2 = - 1000** for Input values:

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0770478607$ bar or

$t < t_{trip} = -259.193$ °C at $p < p_t = 0.0770478607$ bar

$\rho_{max} = 38.148$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0770478607 bar or
at p > 12.837878 bar or p < 0.0770478607 bar and
t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0703991859$ bar or

$t < t_{trip} = -259.35$ °C at $p < p_t = 0.0703991859$ bar

$\rho_{max} = 44.0$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0703991859 bar or
at p > 12.837878 bar or p < 0.0703991859 bar and
t > - 240.212 °C or t < - 259.35 °C

References: [22], [23]

Melting Pressure p_{mel} = f(t, NP)

Function Name: **pmel_t_H2**

Subroutine with function value: **REAL*8 FUNCTION PMELTH2(T,NP)**
for call from Fortran REAL*8 T,NP

Input values:

T - Temperature t in °C

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

PMELTH2, **PMEL or pmel_ptx_H2** - Melting Pressure p_{mel} in bar for H_2 - Para

Range of validity

Temperature range: from - 259.35 °C to - 240.212 °C

Results for wrong input values

Result **PMELH2 = -1000**, **PMEL = -1000** or **pmel_t_H2 = -1000** for Input values:

NP $\neq$ 0

t < - 259.35 °C or t > - 240.212 °C

References: [22]

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

Function Name: **Pr_ptx_H2**

Subroutine with function value: **REAL*8 FUNCTION PRPTXH2(P,T,X,NP)**
for call from Fortran REAL*8 P,T,X,NP

Input values:

P - Pressure *p* in bar

T - Temperature *t* in °C

X - Vapor fraction *x* (kg of saturated steam)/(kg wet steam)

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

PRPTXH2, **PR** or **Pr_ptx_H2** – Prandtl – Number $Pr = \frac{\eta \cdot c_p}{\lambda}$

Range of validity

Temperature range:

H_2 – Para (NP = 0):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal (NP = 1):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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. Here the backward functions will also result in x = -1.

If the state point to be calculated is located in the two phase region (wet steam), either the value 0 or 1 has to be entered for *x* (x = 0 for boiling liquid, x = 1 for saturated steam). Here the backward functions will result in x = 0 or x = 1.

If the state point to be calculated is located in the two phase region, it is adequate to enter either the given value for *t* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* between 0 and 1. When calculating wet steam and *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

H_2 – Normal (NP = 1): Temperature range from $t_t = -259.193$°C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H_2 – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **PRPTXH2 = - 1000**, **PR = -1000** or **Pr_ptx_H2 = - 1000** for Input values:

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t =$ 0.0770478607 bar or

$t < t_{trip} = -259.193$ °C at $p < p_t =$ 0.0770478607 bar

$\rho_{max} =$ 38.148 mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0770478607 bar or
at p > 12.837878 bar or p < 0.0770478607 bar and
t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t =$ 0.0703991859 bar or

$t < t_{trip} = -259.35$ °C at $p < p_t =$ 0.0703991859 bar

$\rho_{max} =$ 44.0 mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0703991859 bar or
at p > 12.837878 bar or p < 0.0703991859 bar and
t > - 240.212 °C or t < - 259.35 °C

References: [22]

Vapor Pressure $p_s = f(t, NP)$

Function Name: **ps_t_H2**

Subroutine with function value: **REAL*8 FUNCTION PSTH2(T,NP)**
for call from Fortran REAL*8 T,NP

Input values:

T - Temperature t in °C

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

PSTH2, **PS** or **ps_t_H2** – Vapor pressure p_s in bar

Range of validity

Temperature range:

H_2 – Normal $(NP = 1)$: Temperature range from $t_t = -259.193$°C to $t_c = -240.212$°C

H_2 – Para $(NP = 0)$: Temperature range from $t_t = -259.35$°C to $t_c = -240.212$°C

Results for wrong input values

Result **PSTH2 = - 1000**, **PS = -1000** or **ps_t_H2 = - 1000** for Input values:

H_2-Para (NP = 0): $t <$ - 259.35 °C or $t >$ - 240.212 °C

H_2-Normal (NP = 1): $t <$ - 259.193 °C or $t >$ - 240.212 °C

References: [22], [23]

Density ρ = f(p, t, x, NP)

Function Name: **rho_ptx_H2**

Subroutine with function value: **REAL*8 FUNCTION RHOPTXH2(P,T,X,NP)**
for call from Fortran REAL*8 P,T,X,NP

Input values:

P - Pressure p in bar

T - Temperature t in °C

X - Vapor fraction x (kg of saturated steam)/(kg wet steam)

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

RHOPTXH2, **RHO** or **rho_ptx_H2** – Density ρ in kg/m^3

Range of validity

Temperature range:

H_2 – Para (NP = 0):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal (NP = 1):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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. Here the backward functions will also result in x = -1.

If the state point to be calculated is located in the two phase region (wet steam), either the value 0 or 1 has to be entered for x (x = 0 for boiling liquid, x = 1 for saturated steam). Here the backward functions will result in x = 0 or x = 1.

If the state point to be calculated is located in the two phase region, it is adequate to enter either the given value for t <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

H_2 – Normal (NP = 1): Temperature range from $t_t = -259.193$°C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H_2 – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **RHOPTXH2 = - 1000**, **RHO = -1000** or **rho_ptx_H2 = - 1000** for Input values:

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0770478607$ bar or

$t < t_{trip} = -259.193$ °C at $p < p_t = 0.0770478607$ bar

$\rho_{max} = 38.148$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0770478607 bar or
at p > 12.837878 bar or p < 0.0770478607 bar and
t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0703991859$ bar or

$t < t_{trip} = -259.35$ °C at $p < p_t = 0.0703991859$ bar

$\rho_{max} = 44.0$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0703991859 bar or
at p > 12.837878 bar or p < 0.0703991859 bar and
t > - 240.212 °C or t < - 259.35 °C

References: [22]

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

Function Name: **s_ptx_H2**

Subroutine with function value: **REAL*8 FUNCTION SPTXH2(P,T,X,NP)**
for call from Fortran REAL*8 P,T,X,NP

Input values:

P - Pressure *p* in bar

T - Temperature *t* in °C

X - Vapor fraction *x* (kg of saturated steam)/(kg wet steam)

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

SPTXH2, **S** or **s_ptx_H2** - Specific entropy *s* in kJ/kg K

Range of validity

Temperature range:

H_2 – Para (NP = 0):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal (NP = 1):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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. Here the backward functions will also result in x = -1.

If the state point to be calculated is located in the two phase region (wet steam), either the value 0 or 1 has to be entered for *x* (x = 0 for boiling liquid, x = 1 for saturated steam). Here the backward functions will result in x = 0 or x = 1.

If the state point to be calculated is located in the two phase region, it is adequate to enter either the given value for *t* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* between 0 and 1. When calculating wet steam and *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

H_2 – Normal (NP = 1): Temperature range from $t_t = -259.193$°C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H_2 – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **SPTXH2 = - 1000**, **S = -1000** or **s_ptx_H2 = - 1000** for Input values:

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0770478607$ bar or

$t < t_{trip} = -259.193$ °C at $p < p_t = 0.0770478607$ bar

$\rho_{max} = 38.148$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0770478607 bar or
at p > 12.837878 bar or p < 0.0770478607 bar and
t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0703991859$ bar or

$t < t_{trip} = -259.35$ °C at $p < p_t = 0.0703991859$ bar

$\rho_{max} = 44.0$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0703991859 bar or
at p > 12.837878 bar or p < 0.0703991859 bar and
t > - 240.212 °C or t < - 259.35 °C

References: [22]

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

Function Name: **t_ph_H2**

Subroutine with function value: **REAL*8 FUNCTION TPHH2(P,H,NP)**
for call from Fortran REAL*8 P,H,NP

Input values:

P - Pressure p in bar

H - Specific enthalpy h in kJ/kg

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

TPHH2, **T** or **t_ph_H2 -** Temperature t in °C

Range of validity

Temperature range:

H_2 – Para (NP = 0):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal (NP = 1):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on the vapor fraction x and wet steam

The wet steam region is calculated automatically by the sub-programs. Using the given values for p and h, the program determines whether the state point to be calculated is located in the single phase region (liquid or superheated steam) or in the wet steam region. After that, the calculation is carried out for the certain region.

Wet steam region:

H_2 – Normal (NP = 1): Pressure range from $p_t =$ 0.0770478607 bar to $p_c = 12.837878$ bar

H_2 – Para (NP = 0): Pressure range from $p_t =$ 0.0703991859 bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **T_PH_H2**, **T = - 1000** or **t_ph_H2 = - 1000** for Input values:

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or
at the calculation result t > 726.85 °C or
$t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0770478607$ bar
$\rho_{max} =$ 38.148 mol / l

Boiling or dew curve:

at p > 12.837878 bar or p < 0.0770478607 bar or

calculation result t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or
at the calculation result t > 726.85 °C or
$t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0703991859$ bar or
$t < t_{trip} = -259.35$ °C at $p < p_t = 0.0703991859$ bar
$\rho_{max} = 44.0$ mol / l

Boiling or dew curve:

at p > 12.837878 bar or p < 0.0703991859 bar or
calculation result t > - 240.212 °C or t < - 259.35 °C

References: [22]

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

Function Name: **t_ps_H2**

Subroutine with function value: **REAL*8 FUNCTION TPSH2(P,S,NP)**
for call from Fortran REAL*8 P,S,NP

Input values:

P - Pressure *p* in bar

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

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

TPSH2, **T** or **t_ps_H2 -** Temperature *t* in °C

Range of validity

Temperature range:

H_2 – Para (NP = 0):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal (NP = 1):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on the vapor fraction x and wet steam

The wet steam region is calculated automatically by the sub-programs. Using the given values for *p* and *s*, the program determines whether the state point to be calculated is located in the single phase region (liquid or superheated steam) or in the wet steam region. After that, the calculation is carried out for the certain region.

Wet steam region:

H_2 – Normal (NP = 1): Pressure range from $p_t =$ 0.0770478607 bar to $p_c = 12.837878$ bar

H_2 – Para (NP = 0): Pressure range from $p_t =$ 0.0703991859 bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **TPSH2, T = - 1000** or **t_ps_H2 = - 1000** for Input values:

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or
at the calculation result t > 726.85 °C or
$t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t =$ 0.0770478607 bar or
$t < t_{trip} = -$ 259.193 °C at $p < p_t =$ 0.0770478607 bar ($\rho_{max} = 38.148$mol/l)

Boiling or dew curve:

at p > 12.837878 bar or p < 0.0770478607 bar or

calculation result t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or
at the calculation result t > 726.85 °C or
$t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t =$ 0.0703991859 bar or
$t < t_{trip} = -$ 259.35 °C at $p < p_t =$ 0.0703991859 bar ($\rho_{max} =$ 44.0 mol/l)

Boiling or dew curve:

at p > 12.837878 bar or p < 0.0703991859 bar or
calculation result t > - 240.212 °C or t < - 259.35 °C

References: [22]

Boiling Temperature $t_s = f(p, NP)$

Function Name: **ts_p_H2**

Subroutine with function value: **REAL*8 FUNCTION TSPH2(P,NP)**
for call from Fortran REAL*8 P,NP

Input values:

P - Pressure p in bar

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

TSPH2, **TS** or **ts_p_H2** – Boiling temperature t_s in °C

Range of validity

Pressure range:

H_2 – Normal $(NP = 1)$: Pressure range from $p_t =$ 0.0770478607 bar to $p_c =$ 12.837878 bar

H_2 – Para $(NP = 0)$: Pressure range from $p_t =$ 0.0703991859 bar to $p_c =$ 12.837878 bar

Results for wrong input values

Result **TSPH2 = - 1000**, **TS = -1000** or **ts_p_H2 = - 1000** for Input values:

H_2-Para (NP = 0): $p <$ 0.0703991859 bar or $p >$ 12.837878 bar

H_2-Normal (NP = 1): $p <$ 0.0770478607 bar or $p >$ 12.837878 bar

References: [22], [23]

Melting Temperature $t_{mel} = f(p, NP)$

Function Name: **tmel_p_H2**

Subroutine with function value: **REAL*8 FUNCTION TMELH2(P,NP)**
for call from Fortran REAL*8 P,NP

Input values:

P - Pressure p in bar

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

TMELH2, **TMEL** or **tmel_p_H2 -** Melting temperature t_{mel} in °C for H2-Para

Range of validity

Pressure range: from 0.0703991859 bar to 1210 bar

Results for wrong input values

Result **TMELH2, = - 1000**, **TMEL = -1000** or **tmel_p_H2 = - 1000** for Input values:

$NP \neq 0$

$p <$ 0.0703991859 bar or $p >$ 1210 bar

References: [22]

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

Function Name: **u_ptx_H2**

Subroutine with function value: **REAL*8 FUNCTION UPTXH2(P,T,X,NP)**
for call from Fortran REAL*8 P,T,X,NP

Input values:

P - Pressure *p* in bar

T - Temperature *t* in °C

X - Vapor fraction *x* (kg of saturated steam)/(kg wet steam)

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

UPTXH2, **U** or **u_ptx_H2** – Specific internal energy *u* in kJ/kg

Range of validity

Temperature range:

H_2 – Para (NP = 0):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal (NP = 1):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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. Here the backward functions will also result in x = -1.

If the state point to be calculated is located in the two phase region (wet steam), either the value 0 or 1 has to be entered for *x* (x = 0 for boiling liquid, x = 1 for saturated steam). Here the backward functions will result in x = 0 or x = 1.

If the state point to be calculated is located in the two phase region, it is adequate to enter either the given value for *t* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* between 0 and 1. When calculating wet steam and *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

H_2 – Normal (NP = 1): Temperature range from $t_t = -259.193$°C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H_2 – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **UPTXH2 = -1000**, **U = -1000** or **u_ptx_H2 = -1000** for Input values:

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0770478607$ bar or

$t < t_{trip} = -259.193$ °C at $p < p_t = 0.0770478607$ bar

$\rho_{max} = 38.148$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0770478607 bar or
at p > 12.837878 bar or p < 0.0770478607 bar and
t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0703991859$ bar or

$t < t_{trip} = -259.35$ °C at $p < p_t = 0.0703991859$ bar

$\rho_{max} = 44.0$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0703991859 bar or
at p > 12.837878 bar or p < 0.0703991859 bar and
t > - 240.212 °C or t < - 259.35 °C

References: [22]

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

Function Name: **v_ptx_H2**

Subroutine with function value: **REAL*8 FUNCTION VPTXH2(P,T,X,NP)**
for call from Fortran REAL*8 P,T,X,NP

Input values:

P - Pressure p in bar

T - Temperature t in °C

X - Vapor fraction x (kg of saturated steam)/(kg wet steam)

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

VPTXH2, **V** or **v_ptx_H2** – Specific volume v in m^3 / kg

Range of validity

Temperature range:

H_2 – Para (NP = 0):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal (NP = 1):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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. Here the backward functions will also result in x = -1.

If the state point to be calculated is located in the two phase region (wet steam), either the value 0 or 1 has to be entered for x (x = 0 for boiling liquid, x = 1 for saturated steam). Here the backward functions will result in x = 0 or x = 1.

If the state point to be calculated is located in the two phase region, it is adequate to enter either the given value for t <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

H_2 – Normal (NP = 1): Temperature range from $t_t = -259.193$°C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H_2 – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **VPTXH2 = - 1000**, **V = - 1000** or **v_ptx_H2 = - 1000** for Input values:

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t =$ 0.0770478607 bar or

$t < t_{trip} = -$ 259.193 °C at $p < p_t =$ 0.0770478607 bar

$\rho_{max} =$ 38.148 mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0770478607 bar or
at p > 12.837878 bar or p < 0.0770478607 bar and
t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t =$ 0.0703991859 bar or

$t < t_{trip} = -$ 259.35 °C at $p < p_t =$ 0.0703991859 bar

$\rho_{max} =$ 44.0 mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0703991859 bar or
at p > 12.837878 bar or p < 0.0703991859 bar and
t > - 240.212 °C or t < - 259.35 °C

References: [22]

Speed of Sound *w* = f(*p*,*t*,*x*,NP)

Function Name: **w_ptx_H2**

Subroutine with function value: **REAL*8 FUNCTION WPTXH2(P,T,X,NP)**
for call from Fortran REAL*8 P,T,X,NP

Input values:

P - Pressure *p* in bar

T - Temperature *t* in °C

X - Vapor fraction *x* (kg of saturated steam)/(kg wet steam)

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

WPTXH2, **W** or **w_ptx_H2 -** Speed of sound *w* in m/s

Range of validity

Temperature range:

H_2 – Para (NP = 0):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal (NP = 1):

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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. Here the backward functions will also result in x = -1.

If the state point to be calculated is located in the two phase region (wet steam), either the value 0 or 1 has to be entered for *x* (x = 0 for boiling liquid, x = 1 for saturated steam). Here the backward functions will result in x = 0 or x = 1.

If the state point to be calculated is located in the two phase region, it is adequate to enter either the given value for *t* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* between 0 and 1. When calculating wet steam and *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

H_2 – Normal (NP = 1): Temperature range from $t_t = -259.193$°C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H_2 – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **WPTXH2 = - 1000** or **w_ptx_H2 = - 1000** for Input values:

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0770478607$ bar or

$t < t_{trip} = -259.193$ °C at $p < p_t = 0.0770478607$ bar

$\rho_{max} = 38.148$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0770478607 bar or
at p > 12.837878 bar or p < 0.0770478607 bar and
t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0703991859$ bar or

$t < t_{trip} = -259.35$ °C at $p < p_t = 0.0703991859$ bar

$\rho_{max} = 44.0$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0703991859 bar or
at p > 12.837878 bar or p < 0.0703991859 bar and
t > - 240.212 °C or t < - 259.35 °C

References: [22]

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

Function Name: **x_ph_H2**

Subroutine with function value: **REAL*8 FUNCTION XPHH2(P,H,NP)**
for call from Fortran REAL*8 P,H,NP

Input values:

P - Pressure *p* in bar

H - Specific enthalpy *h* in kJ/kg

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

XPHH2, **X** or **x_ph_H2 -** Vapor fraction *x* in (kg saturated steam/kg wet steam)

Range of validity

Temperature range:

H_2 – Para $(NP = 0)$:

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal $(NP = 1)$:

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on the calculation of wet steam

The wet steam region is calculated automatically by the sub-programs. Using the given values for *p* and *h*, the program determines whether the state point to be calculated is located in the single phase region (liquid or superheated steam) or in the wet steam region. When calculating wet steam, *x* will be calculated, otherwise the function to be calculated results in x = - 1.

Wet steam region:

H_2 – Normal $(NP = 1)$: Pressure range from $p_t =$ 0.0770478607 bar to $p_c = 12.837878$ bar

H_2 – Para $(NP = 0)$: Pressure range from $p_t =$ 0.0703991859 bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **XPHH2**, **X = - 1** or **x_ph_H2 = - 1** for Input values:

In case the point of state is located in the single phase region

H_2-Para (NP = 0): $p <$ 0.0703991859 bar or $p >$ 12.837878 bar

H_2-Normal (NP = 1): $p <$ 0.0770478607 bar or $p >$ 12.837878 bar

References: [22]

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

Function Name: **x_ps_H2**

Subroutine with function value: **REAL*8 FUNCTION XPSH2(P,S,NP)**
for call from Fortran REAL*8 P,S,NP

Input values:

P - Pressure *p* in bar

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

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

XPSH2, **X** or **x_ps_H2 -** Vapor fraction *x* in (kg saturated steam/kg wet steam)

Range of validity

Temperature range:

H_2 – Para $(NP = 0)$:

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal $(NP = 1)$:

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on the calculation of wet steam

The wet steam region is calculated automatically by the sub-programs. Using the given values for *p* and *s*, the program determines whether the state point to be calculated is located in the single phase region (liquid or superheated steam) or in the wet steam region. When calculating wet steam, *x* will be calculated, otherwise the function to be calculated results in x = - 1.

Wet steam region:

H_2 – Normal $(NP = 1)$: Pressure range from $p_t =$ 0.0770478607 bar to $p_c = 12.837878$ bar

H_2 – Para $(NP = 0)$: Pressure range from $p_t =$ 0.0703991859 bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **XPSH2**, **X = - 1** or **x_ps_H2 = - 1** for Input values:

In case the point of state is located in the single phase region

H_2-Para (NP = 0): $p <$ 0.0703991859 bar or $p >$ 12.837878 bar

H_2-Normal (NP = 1): $p <$ 0.0770478607 bar or $p >$ 12.837878 bar

References: [22]

Speed of Sound $Z = f(p,t,x,NP)$

Function Name: **z_ptx_H2**

Subroutine with function value: **REAL*8 FUNCTION ZPTXH2(P,T,X,NP)**
for call from Fortran REAL*8 P,T,X,NP

Input values:

P - Pressure p in bar

T - Temperature t in °C

X - Vapor fraction x (kg of saturated steam)/(kg wet steam)

NP – Calculation parameter for choosing H_2 – Normal or H_2 – Para

Result

ZPTXH2, **Z** or **z_ptx_H2 –** Compression factor z

Range of validity

Temperature range:

H_2 – Para $(NP = 0)$:

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,

with $\rho_{max} = 44.0$ mol/l ($v_{min} = 0.0112737843$ m^3/kg)

from $t_{trip} = -259.35$°C to 726.85°C at $p \leq p_t = 0.0703991859$ bar

H_2 – Normal $(NP = 1)$:

from $t_{mel}(p)$ or $t_{min} = t(p, \rho_{max})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,

with $\rho_{max} = 38.148$ mol/l ($v_{min} = 0.0130032114$ m^3/kg)

from $t_{trip} = -259.193$°C to 726.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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. Here the backward functions will also result in x = -1.

If the state point to be calculated is located in the two phase region (wet steam), either the value 0 or 1 has to be entered for x (x = 0 for boiling liquid, x = 1 for saturated steam). Here the backward functions will result in x = 0 or x = 1.

If the state point to be calculated is located in the two phase region, it is adequate to enter either the given value for t <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

H_2 – Normal $(NP = 1)$: Temperature range from $t_t = -259.193$°C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H_2 – Para $(NP = 0)$: Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **ZPTXH2 = - 1000** or **z_ptx_H2 = - 1000** for Input values:

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0770478607$ bar or

$t < t_{trip} = -259.193$ °C at $p < p_t = 0.0770478607$ bar

$\rho_{max} = 38.148$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0770478607 bar or
at p > 12.837878 bar or p < 0.0770478607 bar and
t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

$t > 726.85$ °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t = 0.0703991859$ bar or

$t < t_{trip} = -259.35$ °C at $p < p_t = 0.0703991859$ bar

$\rho_{max} = 44.0$ mol / l

Boiling or dew curve:

at p = - 1000 and t > - 240.212 °C or t < - 259.35 °C
at t = - 1000 and p > 12.837878 bar or p < 0.0703991859 bar or
at p > 12.837878 bar or p < 0.0703991859 bar and
t > - 240.212 °C or t < - 259.35 °C

References: [22]

KCE ThermoFluidProperties

KCE-ThermoFluidProperties
www.thermofluidprop.com

Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

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 Thermo-dynamic Derivatives (2008)

Library LibIF97_META

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

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:

CO_2 - Span, Wagner H_2O - IAPWS-95
O_2 - Schmidt, Wagner N_2 - Span et al.
Ar - Tegeler et al.

and of the ideal gases:
SO_2, CO, Ne
(Scientific Formulation of Bücker et al.)

Consideration of:

- Dissociation from VDI 4670
- Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:

- Dry air from Lemmon et al.
- Steam, water and ice from IAPWS-IF97 and IAPWS-06

Consideration of:

- Condensation and freezing of steam
- Dissociation from VDI 4670
- Poynting effect from ASHRAE RP-1485

Extremely Fast Property Calculations

Spline-Based Table Look-up Method (SBTL)

Library LibSBTL_IF97
Library LibSBTL_95
Library LibSBTL_HuAir

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

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

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

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Humid Air

Library ASHRAE LibHuAirProp

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

Consideration of:

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

www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bücker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bücker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

IAPWS Guideline 2001 of Tillner-Roth and Friend (1998)

Helmholtz energy equation for the mixing term

(also useable for calculating the Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

$C_2H_6O_2$	Ethylene glycol
$C_3H_8O_2$	Propylene glycol
C_2H_5OH	Ethanol
CH_3OH	Methanol
$C_3H_8O_3$	Glycerol
K_2CO_3	Potassium carbonate
$CaCl_2$	Calcium chloride
$MgCl_2$	Magnesium chloride
NaCl	Sodium chloride
$C_2H_3KO_2$	Potassium acetate
$CHKO_2$	Potassium formate
LiCl	Lithium chloride
NH_3	Ammonia

Formulation of the International Institute of Refrigeration (IIR 2010)

Ethanol

Library LibC2H5OH

Formulation of
Schroeder et al. (2014)

Methanol

Library LibCH3OH

Formulation of
de Reuck and Craven (1993)

Propane

Library LibPropane

Formulation of
Lemmon et al. (2009)

Siloxanes as ORC Working Fluids

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

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

Tetradecamethylhexasiloxane $C_{14}H_{42}O_5Si_6$ **Library LibMD4M**

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

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_2S **Library LibH2S**

Nitrous oxide N_2O **Library LibN2O**

Sulfur dioxide SO_2 **Library LibSO2**

Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

KCE ThermoFluidProperties

For more information please contact:

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

Internet: www.thermofluidprop.com
Email: info@thermofluidprop.com
Phone: +49-351-27597860
Mobile: +49-172-7914607
Fax: +49-3222-1095810

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

Thermodynamic Properties

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

Transport Properties

- Dynamic viscosity η
- Kinematic viscosity ν
- Thermal conductivity λ
- Prandtl number Pr
- Thermal diffusivity a

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

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

www.thermofluidprop.com

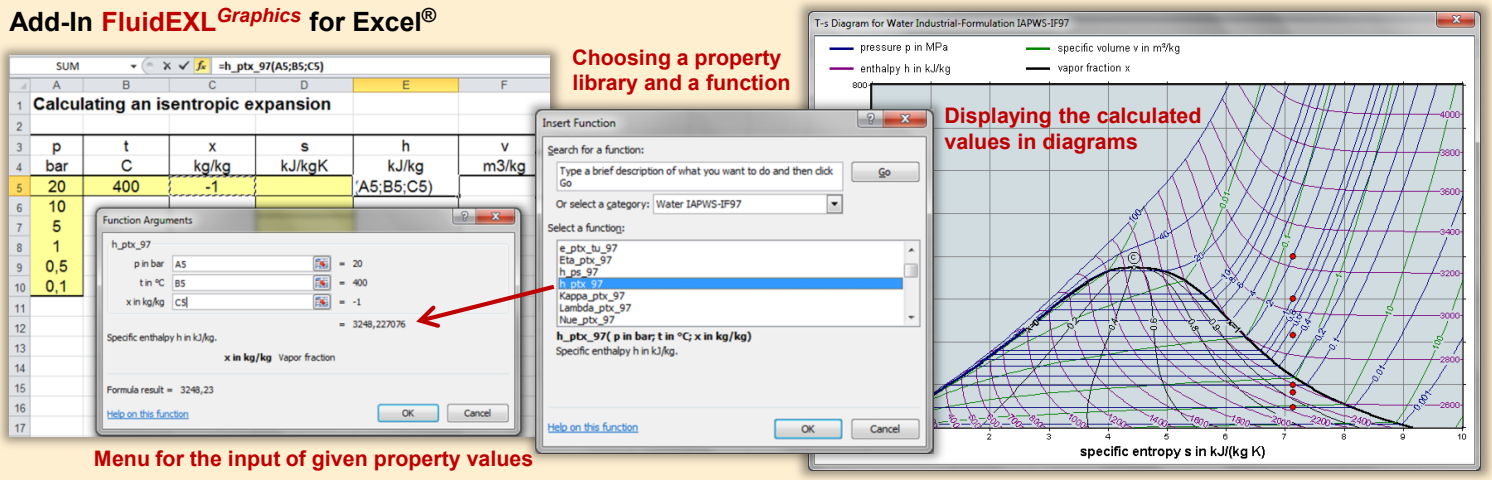
KCE-ThermoFluidProperties
www.thermofluidprop.com

KCE ThermoFluidProperties

Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

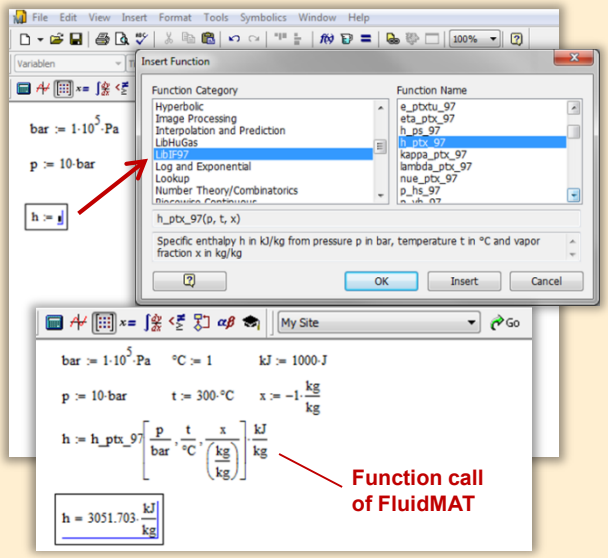
Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Add-In FluidEXL*Graphics* for Excel®



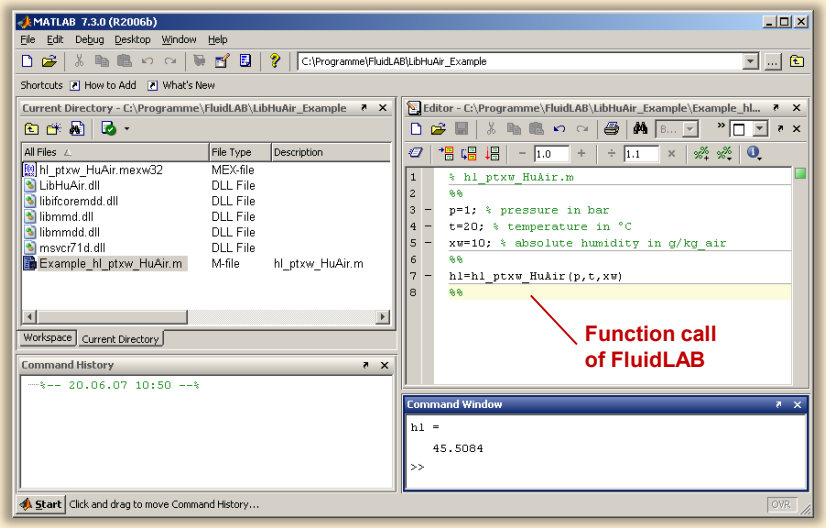
Add-On FluidMAT for Mathcad®
Add-On FluidPRIME for Mathcad Prime®

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



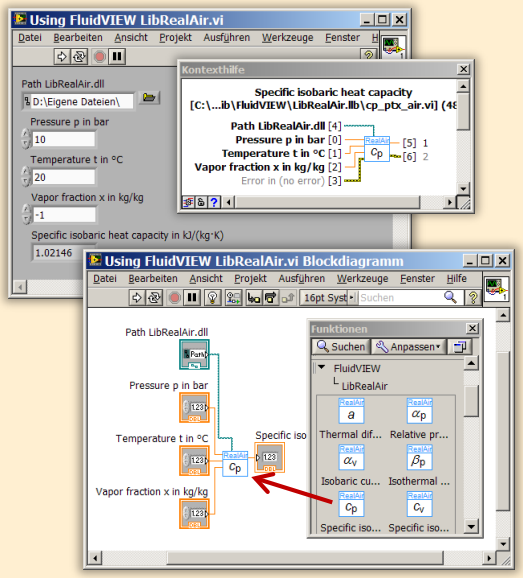
Add-On FluidLAB for MATLAB® and SIMULINK®

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



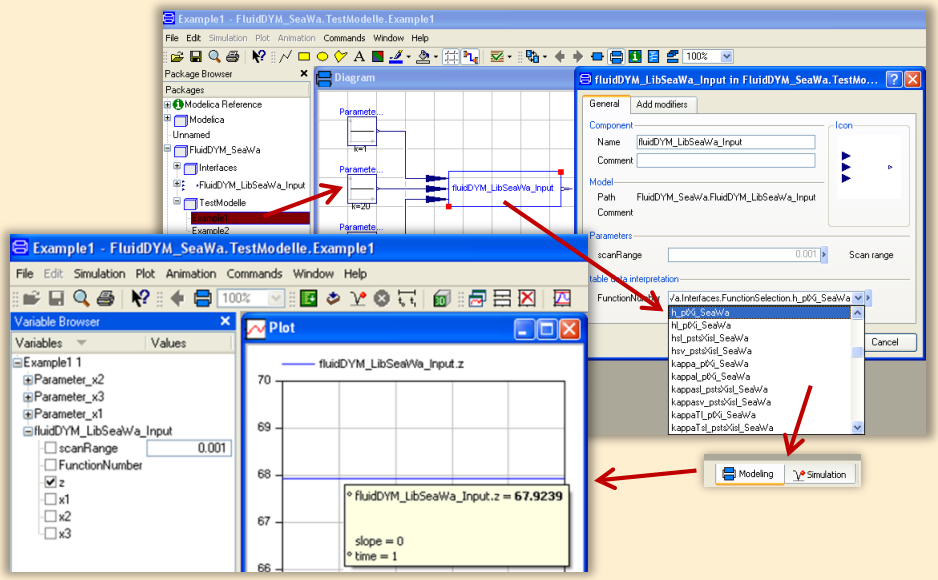
Add-On FluidVIEW for LabVIEW™

The property functions can be calculated in LabVIEW™.

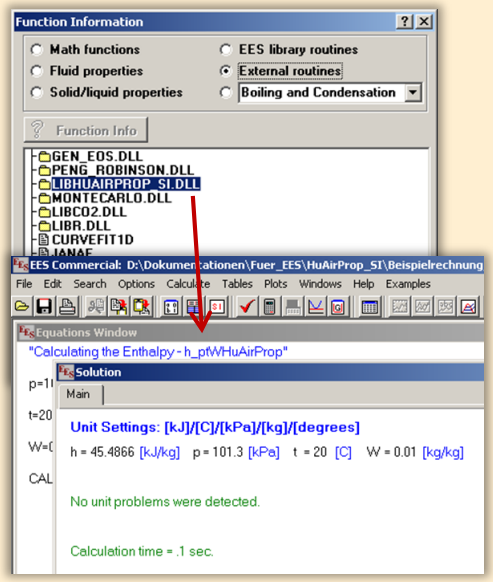


Add-On FluidDYM for DYMOLA® (Modelica) and SimulationX®

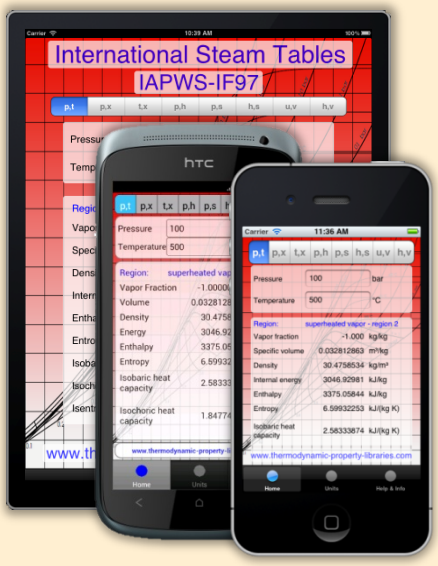
The property functions can be called in DYMOLA® and SimulationX®.



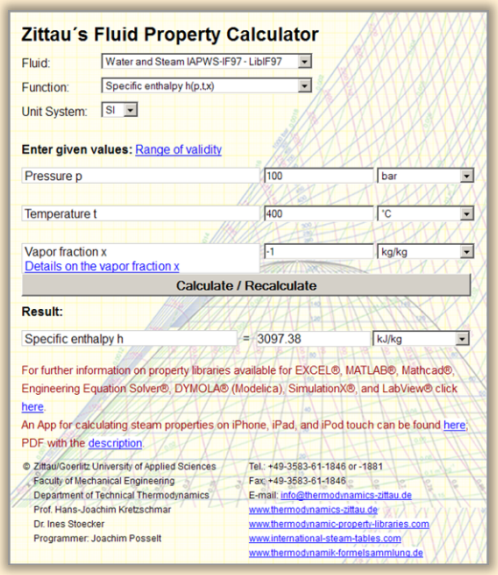
Add-On FluidEES for Engineering Equation Solver®



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



Online Property Calculator at www.thermofluidprop.com



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 Nspire CAS

TI 83
TI 84
TI 89

TI Voyage 200

TI 92

For more information please contact:

KCE ThermoFluidProperties

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

Internet: www.thermofluidprop.com
Email: info@thermofluidprop.com
Phone: +49-351-27597860
Mobile: +49-172-7914607
Fax: +49-3222-1095810

The following thermodynamic and transport properties[a] can be calculated in Excel®, MATLAB®, Mathcad®, Engineering Equation Solver® (EES), DYMOLA® (Modelica), SimulationX® and LabVIEW™:

Thermodynamic Properties

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

Transport Properties

- Dynamic viscosity η
- Kinematic viscosity ν
- Thermal conductivity λ
- Prandtl number Pr
- Thermal diffusivity a

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

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

www.thermofluidprop.com

5. References

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Mollier h,s-Diagramm.
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6. Satisfied Customers

Date: 12/2020

The following companies and institutions use the property libraries:

- FluidEXL*Graphics* for Excel® incl. VBA
- FluidLAB for MATLAB® and Simulink
- FluidMAT for Mathcad®
- FluidPRIME for Mathcad Prime®
- FluidEES for Engineering Equation Solver® EES
- FluidDYM for Dymola® (Modelica) and SimulationX®
- FluidVIEW for LabVIEW™
- FluidPYT for Python
- DLLs for Windows™ Applications
- Shared Objects for Linux®.

2020

Drill Cool, Bakersfield CA,USA	12/2020
Manders, The Netherlands	
RWE Essen	
NEOWAT Lodz, Poland	
University of Duisburg-Essen, Duisburg	11/2020
Stellenbosch University, South Africa	
University De France-COMTe, France	
RWE Essen	
STEAG, Herne	
Isenmann Ingenierbüro	
University of Stuttgart, ITLR, Stuttgart	
Norsk Energi, Norway	
TGM Kanis, Nürnberg	
Stadtwerke Neuburg	10/2020
Smurfit Kappa, Roermond, The Netherlands	
RWE Essen	
Hochschule Zittau/Görlitz, Wirtschaftsingenieurwesen	
Stadtwerke Neuburg	
ILK, Dresden	
ATESTEO, Alsdorf	
Hochschule Zittau/Görlitz, Maschinenwesen	
TH Nürnberg, Verfahrenstechnik	
Drill Cool, Bakersfield CA,USA	09/2020
RWE Essen	
2Meyers Ingenieurbüro, Nürnberg	
FELUWA, Mürlenbach	
Stadtwerke Neuburg	
Caverion, Wien, Austria	

GMVA Niederrhein, Oberhausen	
INWAT Lodz, Poland	
Troche Ingenieurbüro, Hayingen	08/2020
CEA Saclay, France	
VPC, Vetschau	07/2020
FSK System-Kälte-Klima, Dortmund	
Exergie Etudes, Sarl, Switzerland	
AWG Wuppertal	
STEAG Energy Services, Zwingenberg	
Hochschule Braunschweig	06/2020
DBI, Leipzig	
GOHL-KTK, Dumersheim	
TU Dresden, Energieverfahrenstechnik	
BASF SE, ESI/EE, Ludwigshafen	
Wärme Hamburg	
Ruchti Ingenieurbüro, Uster, Switzerland	
IWB, Basel, Switzerland	
Midiplan, Bietingen-Bissingen	05/2020
Knieschke, Ingenieurbüro	
RWE, Essen	
Leser, Hamburg	
AGRANA, Gmünd, Austria	
EWT Wassertechnik, Celle	
Hochschule Darmstadt	04/2020
MTU München CCP	
HAW Hamburg	03/2020
Hanon, Novi Jicin, Czech Republic	
TU Dresden, Kältetechnik	
MAN, Copenhagen, Denmark	
EnerTech, Radebeul	02/2020
LEAG, Cottbus	
B+B Enginering Magdeburg	
Hochschule Offenburg	
WIB, Dennheritz	01/2020
Universität Duisburg-Essen, Strömungsmaschinen	
Kältetechnik Dresen-Bremen	
TH Ingolstadt	
Vattenfall AB, Jokkmokk, Sweden	
Fraunhofer UMSICHT	

2019

PEU Leipzig, Rötha	12/2019
MB-Holding, Vestenbergsgreuth	
RWE, Essen	
Georg-Büchner-Hochschule, Darmstadt	11/2019
EEB ENERKO, Aldenhoven	
Robert Benoufa Energietechnik, Wiesloch	

Kehrein & Kubanek Klimatechnik, Moers	10/2019
Hanon Systems Autopal Services, Hluk, Czech Republic	
CEA Saclay, Gif Sur Yvette cedex, France	
Saudi Energy Efficiency Center SEEC, Riyadh, Saudi Arabia	
VPC, Vetschau	09/2019
jGanser PM + Engineering, Forchheim	
Endress+Hauser Flowtec AG, Reinach, Switzerland	
Ruchti IB, Uster, Switzerland	
ZWILAG Zwischenlager Würenlingen, Switzerland	08/2019
Hochschule Zittau/Görlitz, Faculty Maschinenwesen	
Stadtwerke Neubrandenburg	
Physikalisch Technische Bundesanstalt PTB, Braunschweig	
GMVA Oberhausen	07/2019
Endress+Hauser Flowtec AG, Reinach, Switzerland	
WARNICA, Waterloo, Canada	
MIBRAG, Zeitz	06/2019
Pöyry, Zürich, Switzerland	
RWTH Aachen, Institut für Strahlantriebe und Turbomaschinen	
Midiplan, Bietigheim-Bissingen	
GKS Schweinfurt	
HS Zittau/Görlitz, Wirtschaftswissenschaften und Wirtschaftsingenieurwesen	
ILK Dresden	
HZDR Helmholtz Zentrum Dresden-Rossendorf	
TH Köln, Technische Gebäudeausrüstung	05/2019
IB Knittel, Braunschweig	
Norsk Energi, Oslo, Norway	
STEAG, Essen	
Stora Enso, Eilenburg	
IB Lücke, Paderborn	
Haarslev, Sonderso, Denmark	
MAN Augsburg	
Wieland Werke, Ulm	04/2019
Fels-Werke, Elbingerode	
Univ. Luxembourg, Luxembourg	
BTU Cottbus, Power Engineering	03/2009
Eins-Energie Sachsen, Schwarzenberg	
TU Dresden, Kälte- und Kryotechnik	
ITER, St. Paul Lez Durance Cedex, France	
Fraunhofer UMSICHT, Oberhausen	
Comparex Leipzig for Spedition Thiele HEMMERSBACH	
Rückert NaturGas, Lauf/Pegnitz	
BASF, Basel, Switzerland	02/2019
Stadtwerke Leipzig	
Maerz Ofenbau Zürich, Switzerland	
Hanon Systems Germany, Kerpen	
Thermofin, Heinsdorfergrund	01/2019
BSH Berlin	

2018

Jaguar Energy, Guatemala	12/2018
WEBASTO, Gilching	
Smurfit Kappa, Oosterhout, Netherlands	
Univ. BW München	
RAIV, Liberec for VALEO, Prague, Czech Republic	11/2018
VPC Group Vetschau	
SEITZ, Wetzikon, Switzerland	
MVV, Mannheim	10/2018
IB Troche	
KANIS Turbinen, Nürnberg	
TH Ingolstadt, Institut für neue Energiesysteme	
IB Kristl & Seibt, Graz, Austria	09/2018
INEOS, Köln	
IB Lücke, Paderborn	
Südzucker, Ochsenfurt	08/2018
K&K Turbinenservice, Bielefeld	07/2018
OTH Regensburg, Elektrotechnik	
Comparex Leipzig for LEAG, Berlin	06/2018
Münstermann, Telgte	05/2018
TH Nürnberg, Verfahrenstechnik	
Universität Madrid, Madrid, Spanien	
HS Zittau/Görlitz, Wirtschaftsingenieurwesen	
HS Niederrhein, Krefeld	
Wilhelm-Büchner HS, Pfungstadt	03/2018
GRS, Köln	
WIB, Dennheritz	
RONAL AG, Härklingen, Schweiz	02/2018
Ingenieurbüro Leipert, Riegelsberg	
AIXPROCESS, Aachen	
KRONES, Neutraubling	
Doosan Lentjes, Ratingen	01/2018

2017

Compact Kältetechnik, Dresden	12/2017
Endress + Hauser Messtechnik GmbH +Co. KG, Hannover	
TH Mittelhessen, Gießen	11/2017
Haarslev Industries, Søndersø, Denmark	
Hochschule Zittau/Görlitz, Fachgebiet Energiesystemtechnik	
ATESTEO, Alsdorf	10/2017
Wijbenga, PC Geldermalsen, Netherlands	
Fels-Werke GmbH, Elbingerode	
KIT Karlsruhe, Institute für Neutronenphysik und Reaktortechnik	09/2017
Air-Consult, Jena	
Papierfabrik Koehler, Oberkirch	
ZWILAG, Würenlingen, Switzerland	
TLK-Thermo Universität Braunschweig, Braunschweig	08/2017

Fichtner IT Consulting AG, Stuttgart	07/2017
Hochschule Ansbach, Ansbach	06/2017
RONAL, Härkingen, Switzerland	
BORSIG Service, Berlin	
BOGE Kompressoren, Bielefeld	
STEAG Energy Services, Zwingenberg	
CES clean energy solutions, Wien, Austria	04/2017
Princeton University, Princeton, USA	
B2P Bio-to-Power, Wadersloh	
TU Dresden, Institute for Energy Engineering, Dresden	
SAINT-GOBAIN, Vaujours, France	03/2017
TU Bergakademie Freiberg, Chair of Thermodynamics, Freiberg	
SCHMIDT + PARTNER, Therwil, Switzerland	
KAESER Kompressoren, Gera	
F&R, Praha, Czech Republic	
ULT Umwelt-Lufttechnik, Löbau	02/2017
JS Energie & Beratung, Erding	
Kelvion Brazed PHE, Nobitz-Wilchwitz	
MTU Aero Engines, München	
Hochschule Zittau/Görlitz, IPM	01/2017
CombTec ProCE, Zittau	
SHELL Deutschland Oil, Wesseling	
MARTEC Education Center, Frederikshaven, Denmark	
SynErgy Thermal Management, Krefeld	

2016

BOGE Druckluftsysteme, Bielefeld	12/2016
BFT Planung, Aachen	11/2016
Midiplan, Bietigheim-Bissingen	
BBE Barnich IB	
Wenisch IB,	
INL, Idaho Falls	
TU Kältetechnik, Dresden	
Kopf SynGas, Sulz	
I INL Idaho National Laboratory, Idaho, USA	
NTVEN, Bellevne (USA)	
DREWAG Dresden, Dresden	10/2016
AGO AG Energie+Anlagen, Kulmbach	
Universität Stuttgart, ITW, Stuttgart	09/2016
Pöyry Deutschland GmbH, Dresden	
Siemens AG, Erlangen	
BASF über Fichtner IT Consulting AG	
B+B Engineering GmbH, Magdeburg	
Wilhelm Büchner Hochschule, Pfungstadt	08/2016
Webasto Thermo & Comfort SE, Gliching	
TU Dresden, Dresden	
Endress+Hauser Messtechnik GmbH+Co. KG, Hannover	
D + B Kältetechnik, Althausen	07/2016

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

2015

EES Enerko, Aachen	12/2015
Ruldolf IB, Strau, Austria	
Allborg University, Department of Energie, Aalborg, Denmark	
University of Lyubljana, Slovenia	
Steinbrecht IB, Berlin	11/2015
Universidad Carlos III de Madrid, Madrid, Spain	
STEAK, Essen	
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	
ILK, Dresden	
Schniewindt GmbH & Co. KG, Neuenwalde	08/2015

2014

PROJEKTPLAN, Dohna	04/2014

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

2013

TRANTER-GmbH, Artern	12/2013
SATAKE, Shanghai, China	
STEAG, Herne	
SÜDSALZ, Bad Friedrichshall	
RWE, Essen	
OITH, Kunshan, China	
ULT, Löbau	
MAN, Copenhagen, Dänemark	11/2013
DREWAG, Dresden	
Siemens, Frankenthal	
VGB, Essen	
Haarslev Industries, Herlev, Dänemark	
Fichtner IT, Stuttgart	
RWE, Essen	
STEAG, Herne	
Ingersoll-Rand, Oberhausen	
Wilhelm-Büchner HS, Darmstadt	10/2013
IAV, Chemnitz	
T Siemens, Frankenthal	
echnical University of Regensburg	
PD-Energy, Bitterfeld	09/2013
Thermofin, Heinsdorfergrund	
SHI, New Jersey, USA	
M&M Turbinentechnik, Bielefeld	08/2013
BEG-BHV, Bremerhaven	
ILK, Dresden	

University of Maryland, USA	
TIG-Group, Husum	
RWE, Essen	
University of Budapest, Hungary	
Siemens, Frankenthal	
VGB, Essen	07/2013
Brunner Energieberatung, Zurich, Switzerland	
Technical University of Deggendorf	
University of Maryland, USA	
University of Princeton, USA	
NIST, Boulder, USA	06/2013
IGUS GmbH, Dresden	
BHR Bilfinger, Essen	
SÜDSALZ, Bad Friedrichshall	
Technician School of Berlin	05/2013
KIER, Gajeong-ro, Südkorea	
Schwing/Stetter GmbH, Memmingen	
Vattenfall, Berlin	
AUTARK, Kleinmachnow	
STEAG, Zwingenberg	
Hochtief, Düsseldorf	
University of Stuttgart	04/2013
Technical University -Bundeswehr, Munich	
Rerum Cognitio Forschungszentrum, Frankfurt	
Kältetechnik Dresen + Bremen, Alfhausen	
University Auckland, New Zealand	
MASDAR Institut, Abu Dhabi, United Arab Emirates	03/2013
Simpelkamp, Dresden	02/2013
VEO, Eisenhüttenstadt	
ENTEC, Auerbach	
Caterpillar, Kiel	
Technical University of Wismar	
Technical University of Dusseldorf	
ILK, Dresden	01/2013
Fichtner IT, Stuttgart	
Schnepf Ingeniuerbüro, Nagold	
Schütz Engineering, Wadgassen	
Endress & Hauser, Reinach, Switzerland	
Oschatz GmbH, Essen	
frischli Milchwerke, Rehburg-Loccum	

2012

Voith, Bayreuth	12/2012
Technical University of Munich	
Dillinger Huette	
University of Stuttgart	11/2012
Siemens, Muehlheim	
Fichtner IT, Stuttgart	

Sennheiser, Hannover	
Oschatz GmbH, Essen	10/2012
Fichtner IT, Stuttgart	
Helbling Technik AG, Zurich, Switzerland	
University of Duisburg	
Rerum Cognitio Forschungszentrum, Frankfurt	09/2012
Pöyry Deutschland GmbH, Dresden	08/2012
Extracciones, Guatemala	
RWE, Essen	
Weghaus Consulting Engineers, Wuerzburg	
GKS, Schweinfurt	07/2012
RWE Essen	
SEITZ, Wetzikon, Switzerland	
SPX Balcke-Dürr, Ratingen	
airinotec, Bayreuth	
GEA, Nobitz	
Meyer Werft, Papenburg	
STEAG, Herne	
GRS, Cologne	06/2012
Fichtner IT Consult, Chennai, India	
Siemens, Freiburg	
Nikon Research of America, Belmont, USA	
Niederrhein University of Applied Sciences, Krefeld	
STEAG, Zwingenberg	
Mainova, Frankfurt on Main	05/2012
Endress & Hauser	
Siemens, Erlangen	
PEU, Espenheim	
Luzern University of Applied Sciences, Switzerland	
BASF, Ludwigshafen (general license)	
SPX Balcke-Dürr, Ratingen	
Gruber-Schmidt, Wien, Austria	04/2012
Vattenfall, Berlin	
ALSTOM, Baden	
SKW, Piesteritz	
TERA Ingegneria, Trento, Italy	
Siemens, Erlangen	
LAWI Power, Dresden	
Stadtwerke Leipzig	
SEITZ, Wetzikon, Switzerland	03/2012
M & M, Bielefeld	
Sennheiser, Wedemark	
SPG, Montreuil Cedex, France	02/2012
German Destilation, Sprendlingen	
Lopez, Munguia, Spain	
Endress & Hauser, Hannover	
Palo Alto Research Center, USA	
WIPAK, Walsrode	

Freudenberg, Weinheim	01/2012
Fichtner, Stuttgart	
airinotec, Bayreuth	
University Auckland, New Zealand	
VPC, Vetschau	
Franken Guss, Kitzingen	

2011

XRG-Simulation, Hamburg	12/2011
Smurfit Kappa PPT, AX Roermond, Netherlands	
AWTEC, Zurich, Switzerland	
eins-energie, Bad Elster	
BeNow, Rodenbach	11/2011
Luzern University of Applied Sciences, Switzerland	
GMVA, Oberhausen	
CCI, Karlsruhe	10/2011
W.-Büchner University of Applied Sciences, Pfungstadt	
PLANAIR, La Sagne, Switzerland	
Weihenstephan University of Applied Sciences	
LAWI, Dresden	
Lopez, Munguia, Spain	
University of KwaZulu-Natal, Westville, South Africa	
Voith, Heidenheim	09/2011
SpgBe Montreal, Canada	
Weihenstephan University of Applied Sciences	
SPG TECH, Montreuil Cedex, France	
Voith, Heidenheim-Mergelstetten	
MTU Aero Engines, Munich	08/2011
RWTH Aachen University	
F Technical University of Dresden	
ichtner IT Consulting, Stuttgart	,
MIBRAG, Zeitz	
RWE, Essen	07/2011
Fels, Elingerode	
Weihenstephan University of Applied Sciences	
Forschungszentrum Juelich	
RWTH Aachen University	
INNEO Solutions, Ellwangen	06/2011
Fichtner IT Consulting, Stuttgart	
University of Duisburg	
Technical University of Dresden	
Caliqua, Basel, Switzerland	
Technical University of Freiberg	
Fichtner IT Consulting, Stuttgart	05/2011
Technical University of Dresden	
Salzgitter Flachstahl, Salzgitter	
Helbling Beratung & Bauplanung, Zurich, Switzerland	
INEOS, Cologne	04/2011

Enseleit Consulting Engineers, Siebigerode	
Witt Consulting Engineers, Stade	03/2011
Helbling, Zurich, Switzerland	
MAN Diesel, Copenhagen, Denmark	
AGO, Kulmbach	
University of Duisburg	
CCP, Marburg	
BASF, Ludwigshafen	02/2011
ALSTOM Power, Baden, Switzerland	
Universität der Bundeswehr, Munich	
Calorifer, Elgg, Switzerland	01/2011
STRABAG, Vienna, Austria	
TUEV Sued, Munich	
ILK Dresden	
Technical University of Dresden	

2010

Umweltinstitut Neumarkt	12/2010
YIT Austria, Vienna, Austria	
MCI Innsbruck, Austria	
University of Stuttgart	
HS Cooler, Wittenburg	
MCE, Berlin	
S ILK, Dresden	
iemens Energy, Goerlitz	
Visteon, Novi Jicin, Czech Republic	
CompuWave, Brunntal	
Stadtwerke Leipzig	
MCI Innsbruck, Austria	
EVONIK Energy Services, Zwingenberg	
Caliqua, Basel, Switzerland	11/2010
Shanghai New Energy Resources Science & Technology, China	
Energieversorgung Halle	
Hochschule für Technik Stuttgart, University of Applied Sciences	
Steinmueller, Berlin	
Amberg-Weiden University of Applied Sciences	
AREVA NP, Erlangen	10/2010
MAN Diesel, Augsburg	
KRONES, Neutraubling	
Glen Dimplex, Kulmbach	
Vaillant, Remscheid	
PC Ware, Leipzig	
Schubert Consulting Engineers, Weißenberg	
Fraunhofer Institut UMSICHT, Oberhausen	
Behringer Consulting Engineers, Tagmersheim	09/2010
Saacke, Bremen	
WEBASTO, Neubrandenburg	
Concordia University, Montreal, Canada	

Compañía Eléctrica de Sochagota, Bogota, Colombia	08/2010
Hannover University of Applied Sciences	
ERGION, Mannheim	07/2010
Glen Dimplex, Kulmbach	
Fichtner IT Consulting, Stuttgart	
TF Design, Matieland, South Africa	
MCE, Berlin	
IPM, Zittau/Goerlitz University of Applied Sciences	06/2010
TUEV Sued, Dresden	
RWE IT, Essen	
Glen Dimplex, Kulmbach	05/2010
Hot Rock, Karlsruhe	
D ALSTOM Power, Baden, Switzerland	
armstadt University of Applied Sciences	
Voith, Heidenheim	04/2010
CombTec, Zittau	
University of Glasgow, Great Britain	
Universitaet der Bundeswehr, Munich	
Technical University of Hamburg-Harburg	
Vattenfall Europe, Berlin	
HUBER Consulting Engineers, Berching	
VER, Dresden	
CCP, Marburg	03/2010
Offenburg University of Applied Sciences	
Technical University of Berlin	
NIST Boulder CO, USA	
Technical University of Dresden	02/2010
Siemens Energy, Nuremberg	
Augsburg University of Applied Sciences	
ALSTOM Power, Baden, Switzerland	
MIT Massachusetts Institute of Technology Cambridge MA, USA	
Wieland Werke, Ulm	01/2010
Siemens Energy, Goerlitz	
Technical University of Freiberg	
ILK, Dresden	
Fischer-Uhrig Consulting Engineers, Berlin	

2009

ALSTOM Power, Baden, Schweiz	01/2009
Nordostschweizerische Kraftwerke AG, Doettingen, Switzerland	02/2009
RWE, Neurath	
Brandenburg University of Technology, Cottbus	
Hamburg University of Applied Sciences	
Kehrein, Moers	03/2009
EPP Software, Marburg	
ALSTOM Power, Baden, Schweiz	
Bernd Münstermann, Telgte	
Suedzucker, Zeitz	

CPP, Marburg	
Gelsenkirchen University of Applied Sciences	04/2009
Regensburg University of Applied Sciences	05/2009
ALSTOM Power, Baden, Schweiz	
Gatley & Associates, Atlanta, USA	
BOSCH, Stuttgart	06/2009
Dr. Nickolay, Consulting Engineers, Gommersheim	
Ferrostal Power, Saarlouis	
BHR Bilfinger, Essen	
Intraserv, Wiesbaden	
Lausitz University of Applied Sciences, Senftenberg	
Nuernberg University of Applied Sciences	
Technical University of Berlin	
Fraunhofer Institut UMSICHT, Oberhausen	07/2009
BOSCH, Stuttgart	
Bischoff, Aurich	
Fichtner IT Consulting, Stuttgart	
Techsoft, Linz, Austria	08/2009
DLR, Stuttgart	
Wienstrom, Vienna, Austria	
RWTH Aachen University	09/2009
Vattenfall, Hamburg	10/2009
AIC, Chemnitz	
Midiplan, Bietigheim-Bissingen	11/2009
Institute of Air Handling and Refrigeration ILK, Dresden	
FZD, Rossendorf	
Techgroup, Ratingen	
Robert Sack, Heidelberg	
EC, Heidelberg	
MCI, Innsbruck, Austria	12/2009
Saacke, Bremen	12/2009
ENERKO, Aldenhoven	12/2009

2008

Pink, Langenwang	01/2008
Fischer-Uhrig, Berlin	
University of Karlsruhe	
MAAG, Kuesnacht, Switzerland	02/2008
M&M Turbine Technology, Bielefeld	
Lentjes, Ratingen	03/2008
Siemens Power Generation, Goerlitz	04/2008
Evonik, Zwingenberg (general EBSILON program license)	
WEBASTO, Neubrandenburg	
CFC Solutions, Munich	
RWE IT, Essen	04/2008
Rerum Cognitio, Zwickau	
ARUP, Berlin	05/2008
Rerum Cognitio, Zwickau	

Research Center, Karlsruhe	07/2008
AWECO, Neukirch	
Technical University of Dresden,	
Professorship of Building Services	
Technical University of Cottbus,	
Ingersoll-Rand, Unicov, Czech Republic	08/2008
Technip Benelux BV, Zoetermeer, Netherlands	
Fennovoima Oy, Helsinki, Finland	
Fichtner Consulting & IT, Stuttgart	09/2008
PEU, Espenhain	
Poyry, Dresden	
WINGAS, Kassel	
TUEV Sued, Dresden	10/2008
Technical University of Cottbus,	
Technical University of Dresden,	
AWTEC, Zurich, Switzerland	11/2008
Technical University of Dresden,	
Siemens Power Generation, Erlangen	12/2008

2007

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

Wiesbaden University of Applied Sciences, Endress+Hauser Messtechnik, Hannover	11/2007
University of Rostock, Chair in Technical Thermodynamics	
Siemens Power Generation, Erlangen	
Munich University of Applied Sciences, Rerum Cognitio, Zwickau	12/2007
University of Rostock, Chair in Technical Thermodynamics	

2006

STORA ENSO Sachsen, Eilenburg	01/2006
Technical University of Munich, Chair in Energy Systems	
NUTEC Engineering, Bisikon, Switzerland	
Conwel eco, Bochov, Czech Republic	
Offenburg University of Applied Sciences	
KOCH Transporttechnik, Wadgassen	
BEG Bremerhavener Entsorgungsgesellschaft	02/2006
Deggendorf University of Applied Sciences, University of Stuttgart,	
Siemens Power Generation, Erlangen	
Technical University of Munich,	
Chair in Apparatus and Plant Engineering	
Energietechnik Leipzig (company license),	
Siemens Power Generation, Erlangen	03/2006
RWE Power, Essen	
WAETAS, Pobershau	04/2006
NUTEC Engineering, Bisikon, Switzerland	
Siemens Power Generation, Goerlitz	
Technical University of Braunschweig,	
EnviCon & Plant Engineering, Nuremberg	
Brassel Engineering, Dresden	05/2006
University of Halle-Merseburg, Technical University of Dresden,	
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	
Suedzucker, Ochsenfurt	06/2006
M&M Turbine Technology, Bielefeld	
Feistel Engineering, Volkach	07/2006
ThyssenKrupp Marine Systems, Kiel	
Caliqua, Basel, Switzerland (company license)	09/2006
Atlas-Stord, Rodovre, Denmark	
Konstanz University of Applied Sciences, Siemens Power Generation, Duisburg	10/2006
Hannover University of Applied Sciences, Department of Mechanical Engineering	
Siemens Power Generation, Berlin	11/2006
Zikesch Armaturentechnik, Essen	
Wismar University of Applied Sciences, Seafaring Department	
BASF, Schwarzheide	12/2006
Enertech Energie und Technik, Radebeul	

2005

TUEV Nord, Hannover	01/2005
J.H.K Plant Engineering and Service, Bremerhaven	
Electrowatt-EKONO, Zurich, Switzerland	
FCIT, Stuttgart	
Energietechnik Leipzig (company license)	
eta Energieberatung, Pfaffenhofen	02/2005
FZR Forschungszentrum, Rossendorf/Dresden	04/2005
University of Saarbruecken	
Technical University of Dresden	
Energietechnik Leipzig (company license)	
Grenzebach BSH, Bad Hersfeld	
TUEV Nord, Hamburg	
Technical University of Dresden, Waste Management	05/2005
Siemens Power Generation, Goerlitz	
Duesseldorf University of Applied Sciences,	
Redacom, Nidau, Switzerland	06/2005
Dumas Verfahrenstechnik, Hofheim	
Alensys Engineering, Erkner	07/2005
Energietechnik Leipzig (company license)	
Stadtwerke Leipzig	
SaarEnergie, Saarbruecken	
ALSTOM ITC, Rugby, Great Britain	08/2005
Technical University of Cottbus, Chair in Power Plant Engineering	
Vattenfall Europe, Berlin (group license)	
Technical University of Berlin	10/2005
Basel University of Applied Sciences,	
Midiplan, Bietigheim-Bissingen	11/2005
Technical University of Freiberg, Chair in Hydrogeology	
STORA ENSO Sachsen, Eilenburg	12/2005
Energieversorgung Halle (company license)	
KEMA IEV, Dresden	

2004

Vattenfall Europe (group license)	01/2004
TUEV Nord, Hamburg	
University of Stuttgart, Institute of Thermodynamics and Heat Engineering	02/2004
MAN B&W Diesel A/S, Copenhagen, Denmark	
Siemens AG Power Generation, Erlangen	
Ulm University of Applied Sciences	03/2004
Visteon, Kerpen	
Technical University of Dresden,	
Professorship of Thermic Energy Machines and Plants	04/2004
Rerum Cognitio, Zwickau	
University of Saarbruecken	4
Grenzebach BSH, Bad Hersfeld	
SOFBID Zwingenberg (general EBSILON program license)	
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	
Mainova Frankfurt	
Rietschle Energieplaner, Winterthur, Switzerland	
MAN Turbo Machines, Oberhausen	09/2004
TUEV Sued, Dresden	10/2004
STEAG Kraftwerk, Herne	
University of Weimar	
Visteon, Kerpen	
energeticals (e-concept), Munich	11/2004
SorTech, Halle	
Enertech EUT, Radebeul (company license)	
Munich University of Applied Sciences	12/2004
STORA ENSO Sachsen, Eilenburg	
Technical University of Cottbus, Chair in Power Plant Engineering	
STEAG Kraftwerk, Herne	
Freudenberg Service, Weinheim	

2003

Paper Factory, Utzenstorf, Switzerland	01/2003
MAB Plant Engineering, Vienna, Austria	
Wulff Energy Systems, Husum	
Technip Benelux BV, Zoetermeer, Netherlands	
ALSTOM Power, Baden, Switzerland	
VER, Dresden	02/2003
Rietschle Energieplaner, Winterthur, Switzerland	
DLR, Leupholdhausen	04/2003
Emden University of Applied Sciences, Department of Technology	05/2003
Petterssson+Ahrends, Ober-Moerlen	
SOFBID ,Zwingenberg (general EBSILON program license)	
Ingenieurbuero Ostendorf, Gummersbach	
TUEV Nord, Hamburg	06/2003
Muenstermann GmbH, Telgte-Westbevern	
University of Cali, Colombia	07/2003
ALSTOM Power, Baden, Switzerland	
Atlas-Stord, Rodovre, Denmark	08/2003
ENERKO, Aldenhoven	
STEAG RKB, Leuna	
eta Energieberatung, Pfaffenhofen	
exergie, Dresden	09/2003
AWTEC, Zurich, Switzerland	
Energie, Timelkam, Austria	
Electrowatt-EKONO, Zurich, Switzerland	
LG, Annaberg-Buchholz	10/2003
FZR Forschungszentrum, Rossendorf/Dresden	
EnviCon & Plant Engineering, Nuremberg	11/2003

Visteon, Kerpen	
VEO Vulkan Energiewirtschaft Oderbruecke, Eisenhuettenstadt	
Stadtwerke Hannover	
SaarEnergie, Saarbruecken	
Fraunhofer-Gesellschaft, Munich	12/2003
Erfurt University of Applied Sciences,	
SorTech, Freiburg	
Mainova, Frankfurt	
Energieversorgung Halle	

2002

Hamilton Medical AG, Rhaezuens, Switzerland	01/2002
Bochum University of Applied Sciences,	
SAAS, Possendorf/Dresden	02/2002
Siemens, Karlsruhe	
FZR Forschungszentrum, Rossendorf/Dresden	03/2002
CompAir, Simmern	
GKS Gemeinschaftskraftwerk, Schweinfurt	04/2002
ALSTOM Power Baden, Switzerland (group licenses)	05/2002
InfraServ, Gendorf	
SoftSolutions, Muehlhausen (company license)	
DREWAG, Dresden (company license)	
SOFBID, Zwingenberg (general EBSILON program license)	06/2002
Kleemann Engineering, Dresden	
Caliqua, Basel, Switzerland (company license)	07/2002
PCK Raffinerie, Schwedt (group license)	
Fischer-Uhrig Engineering, Berlin	08/2002
Fichtner Consulting & IT, Stuttgart (company licenses and distribution)	
Stadtwerke Duisburg	
Stadtwerke Hannover	09/2002
Siemens Power Generation, Goerlitz	10/2002
Energieversorgung Halle (company license)	
Bayer, Leverkusen	11/2002
Dillinger Huette, Dillingen	
G.U.N.T. Geraetebau, Barsbuettel (general license and training test benches)	12/2002
VEAG, Berlin	

2001

ALSTOM Power, Baden, Switzerland	01/2001
KW2 B. V., Amersfoot, Netherlands	
Eco Design, Saitamaken, Japan	
M&M Turbine Technology, Bielefeld	
MVV Energie, Mannheim	02/2001
Technical University of Dresden	
PREUSSAG NOELL, Wuerzburg	03/2001
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	04/2001
Muenstermann GmbH, Telgte-Westbevern	05/2001
SaarEnergie, Saarbruecken	

ALSTOM Power, Baden, Switzerland	06/2001
Siemens, Karlsruhegeneral license for the WinIS information system)	08/2001
Neusiedler AG, Ulmerfeld, Austria	09/2001
h s energieanlagen, Freising	
M&M Turbine Technology, Bielefeld	
Electrowatt-EKONO, Zurich, Switzerland	
IPM Zittau/Goerlitz University of Applied Sciences (general license)	10/2001
eta Energieberatung, Pfaffenhofen	11/2001
KW2 B. V., Amersfoot, Netherlands	
ALSTOM Power Baden, Switzerland	12/2001
VEAG, Berlin (group license)	

2000

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

1999

Bayernwerk, Munich	01/1999
DREWAG, Dresden (company license)	02/1999
KEMA IEV, Dresden	03/1999
Regensburg University of Applied Sciences	04/1999
Fichtner Consulting & IT, Stuttgart (company licenses and distribution)	07/1999
Technical University of Cottbus, Chair in Power Plant Engineering	
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	
M&M Turbine Technology Bielefeld	06/1998

B+H Software Engineering Stuttgart	08/1998
Alfa Engineering, Switzerland	09/1998
VEAG Berlin	
NUTEC Engineering, Bisikon, Switzerland	10/1998
SCA Hygiene Products, Munich	
RWE Energie, Neurath	
Wilhelmshaven University of Applied Sciences	
BASF, Ludwigshafen (group license)	11/1998
Energieversorgung, Offenbach	

1997

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