

Property Library for Hydrogen

**FluidMAT
with LibH2
for Mathcad®**

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Software for the Calculation of the Properties of Hydrogen FluidMAT LibH2

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0 Package Contents

Zip-file "CD_FluidMAT_LibH2.zip" includes the following files:

FluidMAT_LibH2_Setup.exe	- Self-extracting and self-installing program
LibH2.dll	- DLL with functions of the LibH2 library
FluidMAT_LibH2_Docu.pdf	- User's Guide

1. Property Functions

Functional Dependence	Function Name	Call from Fortran program	Call in DLL LibH2 as parameter	Property or Function	Unit of the result
$a = f(p, t, x, NP)$	a_ptx_H2	APTXXH2(P,T,X,NP)	C_APTXXH2(A,P,T,X,NP)	Thermal diffusivity	m ² /s
$c_p = f(p, t, x, NP)$	cp_ptx_H2	CPPTXXH2(P,T,X,NP)	C_CPPTXXH2(CP,P,T,X,NP)	Specific isobaric heat capacity	kJ/(kg K)
$c_v = f(p, t, x, NP)$	cp_ptx_H2	CVPTXXH2(P,T,X,NP)	C_CVPTXXH2(CV,P,T,X,NP)	Specific isochoric heat capacity	kJ/(kg K)
$\eta = f(p, t, x, NP)$	eta_ptx_H2	ETAPTXH2(P,T,X,NP)	C_ETAPTXH2(ETA,P,T,X,NP)	Dynamic viscosity	Pa s
$h = f(p, t, x, NP)$	h_ptx_H2	HPTXXH2(P,T,X,NP)	C_HPTXXH2(H,P,T,X,NP)	Specific enthalpy	kJ/kg
$\kappa = f(p, t, x, NP)$	kappa_ptx_H2	KAPPTXXH2(P,T,X,NP)	C_KAPPTXXH2(KAP,P,T,X,NP)	Isentropic exponent	-
$\lambda = f(p, t, x, NP)$	lambda_ptx_H2	LAMPTXXH2(P,T,X,NP)	C_LAMPTXXH2(LAM,P,T,X,NP)	Thermal conductivity	W/(m K)
$\nu = f(p, t, x, NP)$	ny_ptx_H2	NYPTXXH2(P,T,X,NP)	C_NYPTXXH2(NY,P,T,X,NP)	Kinematic viscosity	m ² /s
$p_{\text{mel}} = f(t, NP)$	pmel_t_H2	PMELTH2(T,NP)	C_PMELTH2(PMEL,T,NP)	Melting pressure from temperature	bar
$p_s = f(t, NP)$	ps_t_H2	PSTH2(T,NP)	C_PSTH2(PS,T,NP)	Vapor pressure from temperature	bar
$Pr = f(p, t, x, NP)$	Pr_ptx_H2	PRPTXXH2(P,T,X,NP)	C_PRPTXXH2(PR,P,T,X,NP)	<i>Prandtl</i> -Number	-
$\rho = f(p, t, x, NP)$	rho_ptx_H2	RHOPTXXH2(P,T,X,NP)	C_RHOPTXXH2(RHO,P,T,X,NP)	Density	kg/m ³
$s = f(p, t, x, NP)$	s_ptx_H2	SPTXXH2(P,T,X,NP)	C_SPTXXH2(S,P,T,X,NP)	Specific entropy	kJ/(kg K)
$t = f(p, h, NP)$	t_ph_H2	TPHH2(P,H,NP)	C_TPHH2(T,P,H,NP)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p, s, NP)$	t_ps_H2	TPSH2(P,S,NP)	C_TPSH2(T,P,S,NP)	Backward function: Temperature from pressure and entropy	°C
$t_{\text{mel}} = f(p, NP)$	tmel_p_H2	TMELPH2(P,NP)	C_TMELPH2(TMEL,P,NP)	Melting temperature from pressure	°C
$t_s = f(p, NP)$	ts_p_H2	TSPH2(P,NP)	C_TSPH2(TS,P,NP)	Boiling temperature from pressure	°C
$u = f(p, t, x, NP)$	u_ptx_H2	UPTXXH2(P,T,X,NP)	C_UPTXXH2(U,P,T,X,NP)	Internal energy	kJ/kg
$v = f(p, t, x, NP)$	v_ptx_H2	VPTXXH2(P,T,X,NP)	C_VPTXXH2(V,P,T,X,NP)	Specific volume	m ³ /kg
$w = f(p, t, x, NP)$	w_ptx_H2	WPTXXH2(P,T,X,NP)	C_WPTXXH2(W,P,T,X,NP)	Isentropic speed of sound	m/s ²
$x = f(p, h, NP)$	x_ph_H2	XPHH2(P,H,NP)	C_XPHH2(X,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)	C_XPSH2(X,P,S,NP)	Backward function: Vapor fraction from pressure and entropy	kg/kg

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 H₂-Normal and H₂-Para. The form is specified by the parameter NP.

The parameter NP can take the following values: NP = 1, for H₂-Normal,
 NP = 0, for H₂-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 and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When calculating wet steam and p and t and 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:

H₂-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

H₂-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:

H₂-Para (NP = 0):

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

with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)

from $t_{\text{trip}} = -259.35$ °C to 126.85 °C at $p \leq p_t = 0.0703991859$ bar

H₂-Normal (NP = 1):

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

with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)

from $t_{\text{trip}} = -259.193$ °C to 126.85 °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 H₂-Normal und H₂-Para is based upon the following approximations:

- The specific volume $v = f(p, t)$ for H₂-Normal is also calculated according to the equation of H₂-Para from Younglove [22].
- The equation of vapor pressure from Lemmon [24] for H₂-Para is also used for H₂-Normal.
- The same critical point is taken for H₂-Normal and H₂-Para: $p_c = 12.837878$ bar, $t_c = -240.212$ °C.
- An equation of the melting pressure $p_{\text{mel}} = f(t)$ for H₂-Normal does not exist. The calculable range of state of H₂-Normal is determined by the maximum molar density $\rho_{\text{max}} = 38.148$ mol/l. This corresponds to a minimum specific volume of $v_{\text{min}} = 0.01300321$ m³/kg.
- The range of validity of the equation of state of H₂-Para is confined by the maximum molar density $\rho_{\text{max}} = 44.0$ mol/l. This corresponds to a minimum specific volume of $v_{\text{min}} = 0.0112737843$ m³/kg.

The calculation of the state variables H₂-Normal and H₂-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 Add-In FluidMAT for Mathcad®

The FluidMAT Add-In has been developed to calculate thermodynamic properties in Mathcad® more conveniently.

Within Mathcad® it enables the direct access to functions relating to hydrogen from the LibH2 property library.

2.1 Installing FluidMAT including LibH2

This section describes the installation FluidMAT LibH2.

Before you begin, it is best to uninstall any trial version or full version of FluidMAT delivered before April 2010.

After you have downloaded and extracted the zip-file "CD_FluidMAT_LibH2_Eng.zip", you will see the folder

CD_FluidMAT_LibH2_Eng

in your Windows Explorer®, Norton Commander® etc.

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

Within this folder you will see the following files:

FluidMAT_LibH2_Docu_Eng.pdf

FluidMAT_LibH2_Setup.exe.

In order to run the installation of FluidMAT, including the LibH2 property library, double-click on the file

FluidMAT_LibH2_Setup.exe.

Installation may start with a window noting that all Windows® programs should be closed.

When this is the case, the installation can be continued. Click the "Next >" button.

The Read-Me file window will give you information about the FluidMAT product. Click "Next >" to leave this window.

In the following dialog box, "Choose Destination Location" (see Figure 2.1), the default path where Mathcad® has been installed will be shown:

C:\Program Files\Mathcad\Mathcad 14\.

By clicking the "Browse..." button, you can change the installation directory before installation.

The path will be displayed in the window.

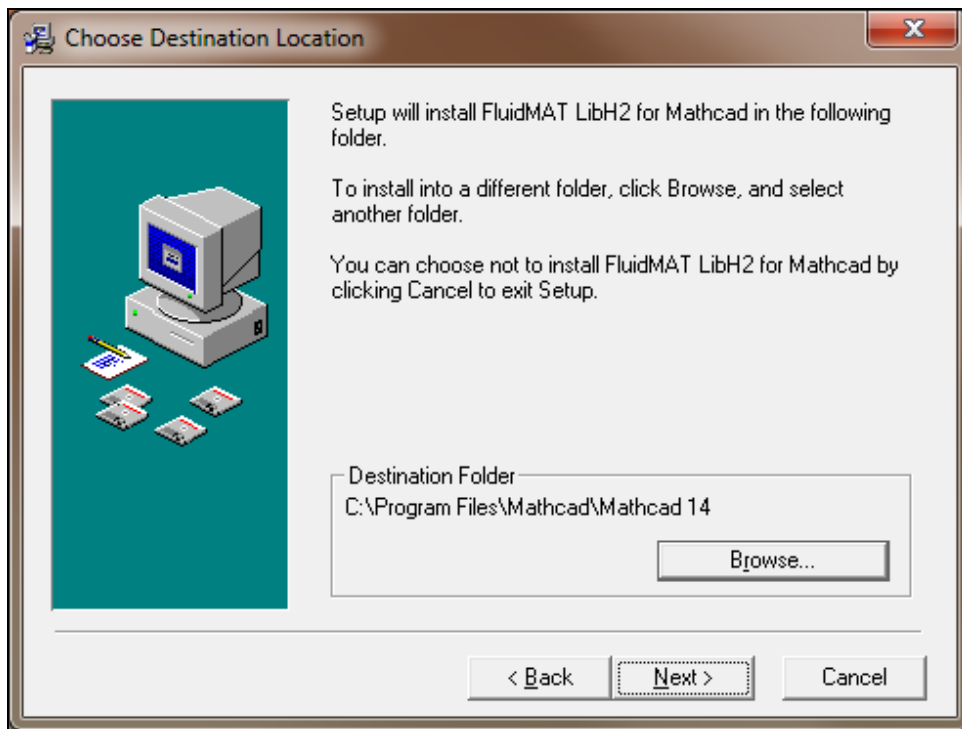


Figure 2.1: "Choose Destination Location"

Click on "Next >" in the window "Choose Destination Location".

Click on the "Next >" button in the "Start Installation" window.

After FluidMAT LibH2 has been installed, the sentence "FluidMAT LibH2 has been successfully installed" will be shown.

Confirm this by clicking the "Finish >" button.

During the installation process the following files are copied into the chosen destination folder (the same folder where Mathcad® was initially installed in):

advapi32.dll	Dynamic link library for use in Windows® programs
Dformd.dll	Dynamic link library for use in Windows® programs
Dforrt.dll	Dynamic link library for use in Windows® programs
INSTALL_MAT_LibH2.LOG	Installation log-file
LC.dll	Dynamic link library for use in Windows® programs
LibH2.dll	Property library for hydrogen
msvcp60.dll	Dynamic link library for use in Windows® programs
msvcrt.dll	Dynamic link library for use in Windows® programs

The following files were installed into your Mathcad® subdirectory \userEFI:

MAT_LibH2.dll	Function definition of LibH2
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The following files were installed into your Mathcad® subdirectory \doc\funcdoc:

MAT_LibH2.xml	Function registration in the dialog window "Insert Function" for LibH2 (Mathcad® version 11 or lower)
MAT_LibH2_DE.xml	Function registration in the dialog window "Insert Function" for LibH2 (German Mathcad® version 12 or higher)
MAT_LibH2_EN.xml	Function registration in the dialog window "Insert Function" for LibH2 (English Mathcad® version 12 or higher)

From within Mathcad® you can now select the LibH2 property functions.

Licensing the LibH2 Property Library

The licensing procedure has to be carried out when you are calculating a function with LibH2 in Mathcad® and a FluidMAT prompt message appears. In this case, you will see the "License Information" window for LibH2 (see figure below).

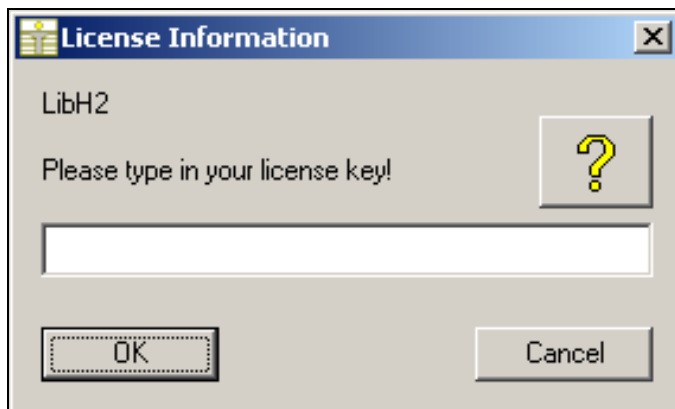


Figure 2.2: "License Information" window

Here you are asked to type in the license key which you have obtained from the Zittau/Goerlitz University of Applied Sciences. If you do not have this, or have any questions, you will find contact information on the "Content" page of this User's Guide or by clicking the yellow question mark in the "License Information" window. Then the following window will appear:



Figure 2.3: "Help" window

If you do not enter a valid license it is still possible to use Mathcad® by clicking "Cancel". In this case, the LibH2 property library will display the result "-11111111" for every calculation.

The "License Information" window will appear every time you use FluidMAT LibH2 until you enter a license code to complete registration. If you decide not to use FluidMAT LibH2, you can uninstall the program following the instructions given in section 2.3 of this User's Guide.

2.2 Example: Calculation of $h = f(p, t, x, NP)$

Now we will calculate, step by step, the specific enthalpy h as a function of pressure p , temperature t , and vapor fraction x , using FluidMAT. We use a calculation in the single phase region here as example to explain how the specific enthalpy h is calculated for H₂-Normal and H₂-Para.

Please carry out the following steps:

- Start Mathcad®.

Type "p:" and enter the value for pressure p in bar

(Range of validity: $p = 0.001 \text{ bar} \dots 1210 \text{ bar}$)

⇒ e.g.: Enter "p:10", then press the tabulator key and enter "in bar".

Note:

When typing in the comment containing the unit of the input parameter, Mathcad switches into the text mode, since you type in a space using the space bar, e.g. "in<space>bar". The text modus is marked by a red cursor instead of a blue one in the math mode. After typing a comment, always finish by positioning the mouse pointer below the variable typed in before and clicking the left mouse button to switch back to math mode.

- Type "t:" and enter the value for temperature t in °C

(Range of validity: $t = t_{\text{mel}} \text{ or } t_{\text{min}} \dots 126.85^\circ\text{C}$)

⇒ e.g.: Enter "t:25", then press the tabulator key and enter "in °C".

- Type "x:" and enter the value for vapor fraction x in kg saturated steam/kg wet steam

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

If the state point to be calculated is located in the single-phase region (liquid or superheated steam), e. g., pressure p and temperature t are given, the value -1 must be entered into the x cell as a pro-forma value.

In case, the state point to be calculated is located in the wet steam region, values between 0 and 1 have to be entered for x (the value 0 for boiling liquid, the value 1 for saturated steam).

Here, it is adequate to enter either the value given for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x between 0 and 1.

However, if p and t and x are given when calculating wet steam, the program initially checks whether p and t meet the saturation-pressure curve. If this is not the case the enthalpy calculated later will result in -1000.

Vapor pressure curve of H₂-Para:

$$t_t = -259.35 \text{ °C} \dots t_c = 240.212 \text{ °C}$$

$$p_t = 0.0703991859 \text{ bar} \dots p_c = 12.837878 \text{ bar}$$

Vapor pressure curve of H₂-Normal:

$$t_t = -259,193 \text{ °C} \dots t_c = 240.212 \text{ °C}$$

$$p_t = 0.0770478607 \text{ bar} \dots p_c = 12.837878 \text{ bar}$$

⇒ e.g.: Enter "x:-1", then press the tabulator key and enter "in kg/kg".

- Type "NP:" and enter a value

Please note that you have to enter the value $NP = 1$ for H₂-Normal.

In case H₂-Para is given, you have to enter the value $NP = 0$. We will calculate H₂-Para separately after this calculation.

⇒ e.g.: Enter "NP:1", then press the Enter key.

The Mathcad® sheet should now look as shown in Figure 2.4.

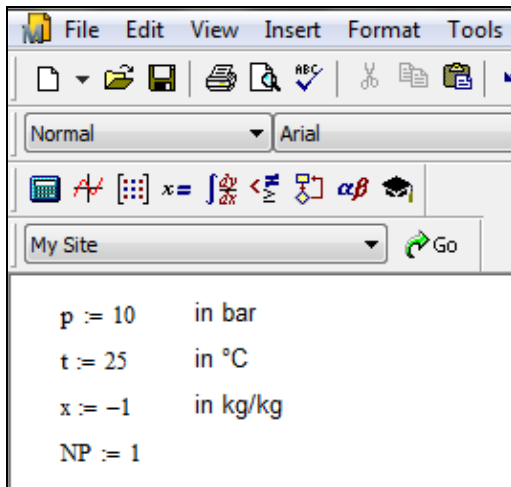


Figure 2.4: Example Mathcad® sheet after input of the given parameters

- Enter the symbol for the result and then a colon
⇒ e.g.: Type "h:".
- Now, click "Insert" in the Mathcad® menu bar and then "Function..."
The "Insert Function" window appears (see Figure 2.5)
- Click "LibH2" under "Function Category" on the left hand side
(see Figure 2.5)
- Choose "h_ptx_H2" under "Function Name" on the right hand side

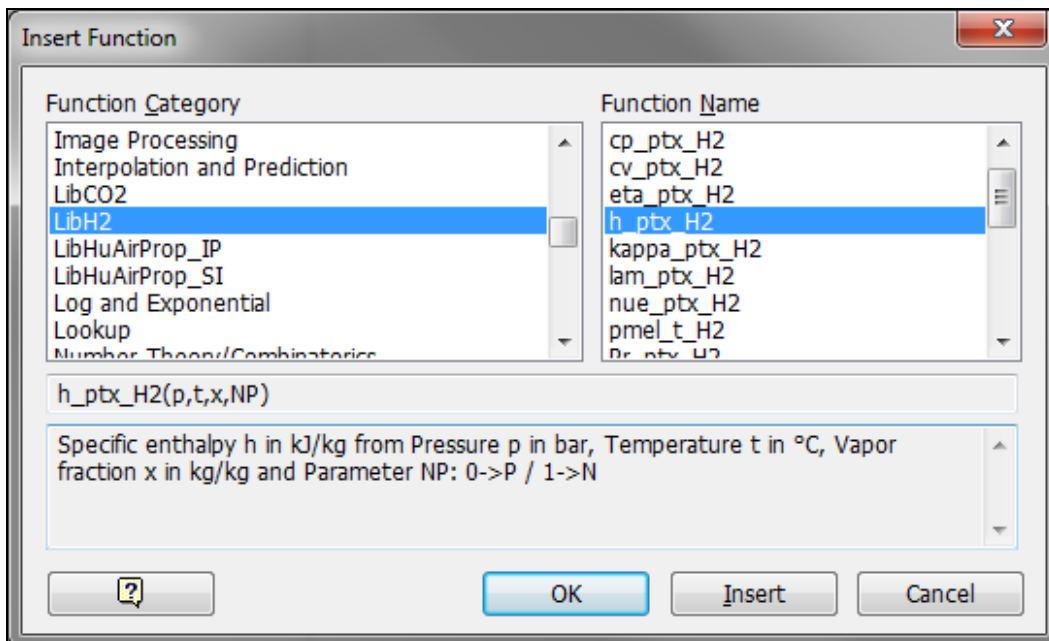


Figure 2.5: Choice of library and function name

- Click the "OK" button.
Now you will see the line "**h_ptx_H2(■,■,■,■)**" in the Mathcad® window
(see Figure 2.6).

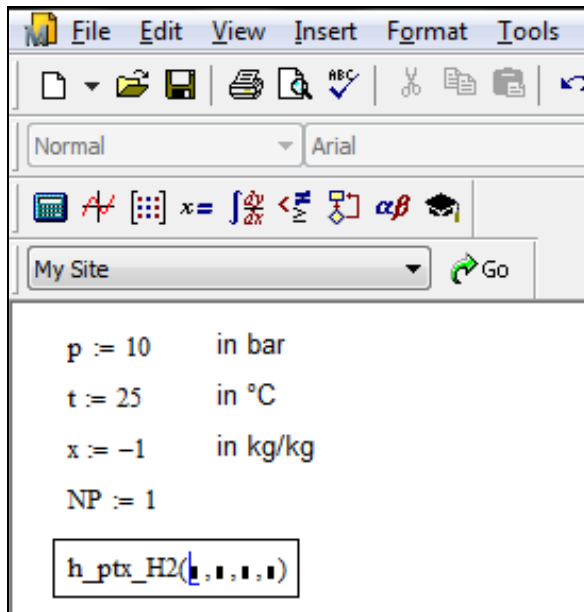


Figure 2.6: Example Mathcad® sheet with formula and placeholders

- The cursor is now situated on the first operand. You can now enter the value for p either by entering the value directly or by entering the name of the variable where the value was saved.

⇒ e.g.: Enter "p".

- Situate the cursor on the next placeholder. You can now enter the value for the temperature t either by entering the value for t directly or by typing the name of the variable in which the value of the temperature has been saved.

⇒ e.g.: Enter "t".

- Situate the cursor on the next placeholder. You can now enter the value for the vapor fraction x either by entering the value for x directly or by typing the name of the variable in which the value of the vapor fraction has been saved.

⇒ e.g.: Enter "x".

Situate the cursor on the next placeholder. You can now enter the value for NP either by entering the value for NP directly or by typing the name of the variable in which the value has been saved.

⇒ e.g.: Enter "NP".

- Close the input formula by pressing the "Enter" key.
- You can now go on working with the variable h which we have just calculated, or you can have the result for this calculated. If you wish to see the result, type the command "**h=**" on the next line in the Mathcad® window.
- The result for h in kJ/kg appears. To add the unit, press the tabulator key twice and enter "in kJ/kg".

⇒ The result in our sample calculation here is: $h = 3935.56962$ in kJ/kg.

The representation of the result depends on the number of decimal places which you have set in Mathcad.

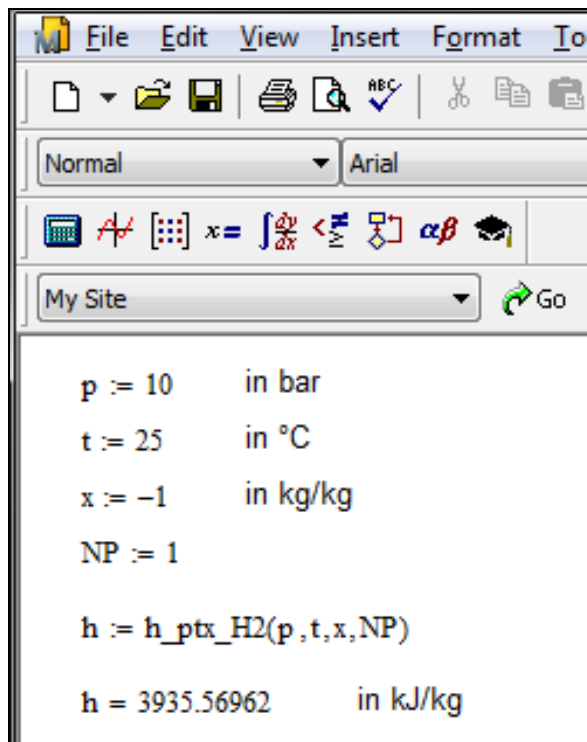


Figure 2.7: Example Mathcad® sheet with finished calculation

The calculation of $h = f(p, t, x, NP)$ has been carried out.

You can now change the value for NP by replacing the value 1 (H₂-Normal) with 0 (H₂-Para).

Press the Enter key after your input.

The specific enthalpy will be recalculated and updated. You will see the new result for h .

⇒ [The result in our sample calculation here is: \$h = 4433.97094\$ in kJ/kg.](#)

You can now go on and arbitrarily change the values for p , t , x , and NP (1;0). The specific enthalpy is recalculated and updated every time you change the data. This shows that the Mathcad® data flow and the DLL calculations are working together successfully.

2.3 Removing FluidMAT including LibH2

To remove FluidMAT LibH2 from Mathcad® and your hard drive, carry out the following steps:

- Click the "Start" button in the Windows® task bar
- Click "Settings"
- Click "Control Panel"
- Double click "Add or Remove Programs"
- Click on "FluidMAT LibH2" in the list box
- Click the "Add or Remove" button
- Mark "Automatic" and click the "Next >" button
- Click "Finish" in the "Perform Uninstall" window

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

Now FluidMAT LibH2 has been removed.

3. Program Documentation

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

Function Name: **a_ptx_H2**

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

Subroutine with parameter:
for call from DLL **INTEGER*4 FUNCTION C_APTXH2(A,P,T,X,NP)**
REAL*8 A,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 H₂ - Normal or H₂ - Para

Result

APTXH2, A or a_ptx_H2 - Thermal diffusivity $a = \frac{\lambda \cdot v}{c_p}$ in m²/s

Range of validity

Temperature range:

H₂ - Para (NP = 0):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,
 with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)
 from $t_{\text{trip}} = -259.35$ °C to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ - Normal (NP = 1):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193$ °C to 126.85°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 and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When calculating wet steam and p and t and 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:

3/2

H₂ – Normal (NP = 1): Temperature range from $t_t = -259.193^\circ\text{C}$ to $t_c = -240.212^\circ\text{C}$
Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H₂ – Para (NP = 0): Temperature range from $t_t = -259.35^\circ\text{C}$ to $t_c = -240.212^\circ\text{C}$
Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

Result **APT_XH2 = -1000**, **A = -1000** or **a_ptx_H2 = -1000** for Input values:

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

$p > 1210$ bar or $p < 0.001$ bar or
 $t > 126.85^\circ\text{C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0770478607$ bar or
 $t < t_{\text{trip}} = -259.193^\circ\text{C}$ at $p < p_t = 0.0770478607$ bar
 $\rho_{\text{max}} = 38.148$ mol/l

Boiling or dew curve:

at $p = -1000$ and $t > -240.212^\circ\text{C}$ or $t < -259.35^\circ\text{C}$
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
 $t > -240.212^\circ\text{C}$ or $t < -259.193^\circ\text{C}$

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

$p > 1210$ bar or $p < 0.001$ bar or
 $t > 126.85^\circ\text{C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0703991859$ bar or
 $t < t_{\text{trip}} = -259.35^\circ\text{C}$ at $p < p_t = 0.0703991859$ bar
 $\rho_{\text{max}} = 44.0$ mol/l

Boiling or dew curve:

at $p = -1000$ and $t > -240.212^\circ\text{C}$ or $t < -259.35^\circ\text{C}$
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
 $t > -240.212^\circ\text{C}$ or $t < -259.35^\circ\text{C}$

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**

Subroutine with parameter: **INTEGER*4 FUNCTION C_CPPTXH2(CP,P,T,X,NP)**
for call from DLL **REAL*8 CP,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 H₂ - Normal or H₂ - Para

Result

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

Range of validity

Temperature range:

H₂ - Para (NP = 0):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,
 with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)
 from $t_{\text{trip}} = -259.35$ °C to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ - Normal (NP = 1):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193$ °C to 126.85°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 and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When calculating wet steam and p and t and 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:

H₂ - 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

H₂ - 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:

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

$p > 1210$ bar or $p < 0.001$ bar or

$t > 126.85$ °C or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0770478607$ bar or

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

$\rho_{\text{max}} = 38.148$ 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

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

$p > 1210$ bar or $p < 0.001$ bar or

$t > 126.85$ °C or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0703991859$ bar or

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

$\rho_{\text{max}} = 44.0$ 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**
 Subroutine with parameter: **INTEGER*4 FUNCTION C_CVPTXH2(CV,P,T,X,NP)**
 for call from DLL **REAL*8 CV,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 H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,
 with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)
 from $t_{\text{trip}} = -259.35$ °C to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ – Normal (NP = 1):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193$ °C to 126.85°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 and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When calculating wet steam and p and t and 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:

H₂ – 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
 H₂ – 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:

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0770478607 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.193 \text{ °C}$

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0703991859 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

References: [22]

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

Function Name: **eta_ptx_H2**

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

Subroutine with parameter:
for call from DLL **INTEGER*4 FUNCTION C_ETAPTXH2(ETA,P,T,X,NP)**
REAL*8 ETA,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 H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,
 with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)
 from $t_{\text{trip}} = -259.35$ °C to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ – Normal (NP = 1):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193$ °C to 126.85°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 and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When calculating wet steam and p and t and 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:

H₂ – 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

H₂ – 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:

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0770478607 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.193 \text{ °C}$

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0703991859 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

References: [22], [23]

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

Function Name: **h_ptx_H2**

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

Subroutine with parameter:
for call from DLL **INTEGER*4 FUNCTION C_HPTXH2(H,P,T,X,NP)**
REAL*8 H,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 H₂ - Normal or H₂ - Para

Result

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

Range of validity

Temperature range:

H₂ - Para (NP = 0):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,
 with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)
 from $t_{\text{trip}} = -259.35$ °C to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ - Normal (NP = 1):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193$ °C to 126.85°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 and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When calculating wet steam and p and t and 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:

H₂ - 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

H₂ - 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:

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0770478607 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.193 \text{ °C}$

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0703991859 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

References: [22]

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

Function Name: **kappa_ptx_H2**

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

Subroutine with parameter:
for call from DLL **INTEGER*4 FUNCTION C_KAPPTXH2(KAP,P,T,X,NP)**
REAL*8 KAP,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 H₂ - Normal or H₂ - Para

Result

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

Range of validity

Temperature range:

H₂ - Para (NP = 0):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,
 with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)
 from $t_{\text{trip}} = -259.35$ °C to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ - Normal (NP = 1):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193$ °C to 126.85°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 and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When calculating wet steam and p and t and 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:

H₂ - 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

H₂ - 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:

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0770478607 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.193 \text{ °C}$

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0703991859 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

References: [22]

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

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**

Subroutine with parameter: **INTEGER*4 FUNCTION C_LAMPTXH2(LAM,P,T,X,NP)**
for call from DLL **REAL*8 LAM,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 H₂ - Normal or H₂ - Para

Result

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

Range of validity

Temperature range:

H₂ - Para (NP = 0):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,
 with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)
 from $t_{\text{trip}} = -259.35$ °C to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ - Normal (NP = 1):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193$ °C to 126.85°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 and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When calculating wet steam and p and t and 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:

H₂ - 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

H₂ - 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:

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0770478607 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.193 \text{ °C}$

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0703991859 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

References: [22], [23]

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

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**

Subroutine with parameter: **INTEGER*4 FUNCTION C_NYPTXH2(NY,P,T,X,NP)**
for call from DLL **REAL*8 NY,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 H₂ - Normal or H₂ - Para

Result

NYPTXH2, NY or ny_ptx_H2 - Kinematic viscosity $\nu = \eta \cdot \nu$ in m²/s

Range of validity

Temperature range:

H₂ - Para (NP = 0):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,
 with $\rho_{\text{max}} = 44.0$ mol/l ($\nu_{\text{min}} = 0.0112737843$ m³/kg)
 from $t_{\text{trip}} = -259.35$ °C to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ - Normal (NP = 1):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($\nu_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193$ °C to 126.85°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 and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When calculating wet steam and p and t and 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:

H₂ - 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

H₂ - 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:

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0770478607 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.193 \text{ °C}$

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0703991859 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

References: [22], [23]

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

Function Name:	pmel_t_H2
Subroutine with function value: for call from Fortran	REAL*8 FUNCTION PMELTH2(T,NP) REAL*8 T,NP
Subroutine with parameter: for call from DLL	INTEGER*4 FUNCTION C_PMELH2(PMEL,T,NP) REAL*8 PMEL, T,NP

Input values:

T - Temperature t in °C

NP – Calculation parameter for choosing H₂ – Normal or H₂ – Para

Result

PMELTH2, PMEL or pmel_ptx_H2 - Melting Pressure p_{mel} in bar for H₂ - 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 ≠ 0

$t < - 259.35 \text{ °C}$ or $t > - 240.212 \text{ °C}$

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**

Subroutine with parameter: **INTEGER*4 FUNCTION C_PRPTXH2(PR,P,T,X,NP)**
 for call from DLL **REAL*8 PR,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 H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):
 from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,
 with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)
 from $t_{\text{trip}} = -259.35$ °C to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ – Normal (NP = 1):
 from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193$ °C to 126.85°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 and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When calculating wet steam and p and t and 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:

H₂ – 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

H₂ – 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:

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0770478607 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.193 \text{ °C}$

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0703991859 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

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**
 Subroutine with parameter: **INTEGER*4 FUNCTION C_PSTH2(PS,T,NP)**
 for call from DLL **REAL*8 PS,T,NP**

Input values:

T - Temperature t in °C

NP – Calculation parameter for choosing H₂ – Normal or H₂ – Para

Result

PSTH2, PS or ps_t_H2 – Vapor pressure p_s in bar

Range of validity

Temperature range:

H₂ – Normal (NP = 1): Temperature range from $t_t = -259.193^\circ\text{C}$ to $t_c = -240.212^\circ\text{C}$

H₂ – Para (NP = 0): Temperature range from $t_t = -259.35^\circ\text{C}$ to $t_c = -240.212^\circ\text{C}$

Results for wrong input values

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

H₂-Para (NP = 0): $t < -259.35^\circ\text{C}$ or $t > -240.212^\circ\text{C}$

H₂-Normal (NP = 1): $t < -259.193^\circ\text{C}$ or $t > -240.212^\circ\text{C}$

References: [22], [23]

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

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**

Subroutine with parameter: **INTEGER*4 FUNCTION C_RHOPTXH2(RHO,P,T,X,NP)**
 for call from DLL **REAL*8 RHO,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 H₂ - Normal or H₂ - Para

Result

RHOPTXH2, RHO or rho_ptx_H2 - Density ρ in kg/m³

Range of validity

Temperature range:

H₂ - Para (NP = 0):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,
 with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)
 from $t_{\text{trip}} = -259.35$ °C to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ - Normal (NP = 1):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193$ °C to 126.85°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 and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When calculating wet steam and p and t 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:

H₂ - 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

H₂ - 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:

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0770478607 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.193 \text{ °C}$

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0703991859 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

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**

Subroutine with parameter: **INTEGER*4 FUNCTION C_SPTXH2(S,P,T,X,NP)**
 for call from DLL **REAL*8 S,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 H₂ - Normal or H₂ - Para

Result

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

Range of validity

Temperature range:

H₂ - Para (NP = 0):

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

with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)

from $t_{\text{trip}} = -259.35$ °C to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ - Normal (NP = 1):

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

with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)

from $t_{\text{trip}} = -259.193$ °C to 126.85°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 and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When calculating wet steam and p and t and 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:

H₂ - 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

H₂ - 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:

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0770478607 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.193 \text{ °C}$

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0703991859 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

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**
 Subroutine with parameter: **INTEGER*4 FUNCTION C_TPHH2(T,P,H,NP)**
 for call from DLL **REAL*8 T,P,H,NP**

Input values:

P - Pressure p in bar
H - Specific enthalpy h in kJ/kg
NP - Calculation parameter for choosing H₂ – Normal or H₂ – Para

Result

TPHH2, T or t_ph_H2 - Temperature t in °C

Range of validity

Temperature range:

H₂ – Para (NP = 0):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,
 with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)
 from $t_{\text{trip}} = -259.35$ °C to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ – Normal (NP = 1):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193$ °C to 126.85°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:

H₂ – Normal (NP = 1): Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H₂ – 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:

H₂-Normal (NP = 1):

Single phase region:

($x = - 1$)

$p > 1210$ bar or $p < 0.001$ bar or
 at the calculation result $t > 126.85$ °C or
 $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0770478607$ bar
 $\rho_{\text{max}} = 38.148$ 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

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

$p > 1210$ bar or $p < 0.001$ bar or

at the calculation result $t > 126.85$ °C or

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

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

$\rho_{\text{max}} = 44.0$ 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**
 Subroutine with parameter: **INTEGER*4 FUNCTION C_TPSH2(T,P,S,NP)**
 for call from DLL **REAL*8 T,P,S,NP**

Input values:

P - Pressure p in bar
S - Specific entropy s in kJ/(kg K)
NP - Calculation parameter for choosing H₂ – Normal or H₂ – Para

Result

TPSH2, T or t_ps_H2 - Temperature t in °C

Range of validity

Temperature range:

H₂ – Para (NP = 0):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,
 with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)
 from $t_{\text{trip}} = -259.35$ °C to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ – Normal (NP = 1):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193$ °C to 126.85°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:

H₂ – Normal (NP = 1): Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H₂ – 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:

H₂-Normal (NP = 1):

Single phase region:

($x = - 1$)

$p > 1210$ bar or $p < 0.001$ bar or
 at the calculation result $t > 126.85$ °C or
 $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0770478607$ bar or
 $t < t_{\text{trip}} = - 259.193$ °C at $p < p_t = 0.0770478607$ bar ($\rho_{\text{max}} = 38.148$ 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

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

$p > 1210$ bar or $p < 0.001$ bar or

at the calculation result $t > 126.85$ °C or

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

$t < t_{\text{trip}} = -259.35$ °C at $p < p_t = 0.0703991859$ bar ($\rho_{\text{max}} = 44.0$ 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:
for call from Fortran **REAL*8 FUNCTION TSPH2(P,NP)**
REAL*8 P,NP

Subroutine with parameter:
for call from DLL **INTEGER*4 FUNCTION C_TSPH2(TS,P,NP)**
REAL*8 TS,P,NP

Input values:

P - Pressure p in bar

NP – Calculation parameter for choosing H₂ – Normal or H₂ – Para

Result

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

Range of validity

Pressure range:

H₂ – Normal (NP = 1): Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H₂ – 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:

H₂-Para (NP = 0): $p < 0.0703991859$ bar or $p > 12.837878$ bar

H₂-Normal (NP = 1): $p < 0.0770478607$ bar or $p > 12.837878$ bar

References: [22], [23]

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

Function Name: **tmel_p_H2**

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

Subroutine with parameter: **INTEGER*4 FUNCTION C_TMELH2(TMEL,P,NP)**
 for call from DLL **REAL*8 TMEL,P,NP**

Input values:

P - Pressure p in bar

NP – Calculation parameter for choosing H₂ – Normal or H₂ – 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:

$\text{NP} \neq 0$

$p < 0.0703991859 \text{ bar}$ or $p > 1210 \text{ bar}$

References: [22]

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

Function Name: **u_ptx_H2**

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

Subroutine with parameter:
for call from DLL **INTEGER*4 FUNCTION C_UPTXH2(U,P,T,X,NP)**
REAL*8 U,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 H₂ - Normal or H₂ - Para

Result

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

Range of validity

Temperature range:

H₂ - Para (NP = 0):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,
 with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)
 from $t_{\text{trip}} = -259.35$ °C to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ - Normal (NP = 1):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193$ °C to 126.85°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 and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When calculating wet steam and p and t and 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:

H₂ - 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

H₂ - 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:

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0770478607 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.193 \text{ °C}$

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0703991859 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

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**

Subroutine with parameter: **INTEGER*4 FUNCTION C_VPTXH2(V,P,T,X,NP)**
 for call from DLL **REAL*8 V,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 H₂ - Normal or H₂ - Para

Result

VPTXH2, V or v_ptx_H2 - Specific volume v in m³ / kg

Range of validity

Temperature range:

H₂ - Para (NP = 0):
 from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,
 with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)
 from $t_{\text{trip}} = -259.35$ °C to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ - Normal (NP = 1):
 from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193$ °C to 126.85°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 and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When calculating wet steam and p and t and 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:

H₂ - 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

H₂ - 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:

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0770478607 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.193 \text{ °C}$

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0703991859 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

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**

Subroutine with parameter: **INTEGER*4 FUNCTION C_WPTXH2(W,P,T,X,NP)**
 for call from DLL **REAL*8 W,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 H₂ - Normal or H₂ - Para

Result

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

Range of validity

Temperature range:

H₂ - Para (NP = 0):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,
 with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)
 from $t_{\text{trip}} = -259.35$ °C to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ - Normal (NP = 1):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193$ °C to 126.85°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 and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When calculating wet steam and p and t and 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:

H₂ - 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

H₂ - 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:

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0770478607 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.193 \text{ °C}$

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

$p > 1210 \text{ bar}$ or $p < 0.001 \text{ bar}$ or

$t > 126.85 \text{ °C}$ or $t < t_{\text{mel}}(p)$ or $t < t(p, \rho_{\text{max}})$ at $p \geq p_t = 0.0703991859 \text{ bar}$ or

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

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

at $t = -1000$ and $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ or

at $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ and

$t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

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**
 Subroutine with parameter: **INTEGER*4 FUNCTION C_XPHH2(T,P,H,NP)**
 for call from DLL **REAL*8 X,P,H,NP**

Input values:

P - Pressure p in bar
H - Specific enthalpy h in kJ/kg
NP - Calculation parameter for choosing H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,
 with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)
 from $t_{\text{trip}} = -259.35^\circ\text{C}$ to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ – Normal (NP = 1):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193^\circ\text{C}$ to 126.85°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:

H₂ – Normal (NP = 1): Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H₂ – 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

H₂-Para (NP = 0): $p < 0.0703991859$ bar or $p > 12.837878$ bar

H₂-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**
 Subroutine with parameter: **INTEGER*4 FUNCTION C_XPSH2(X,P,S,NP)**
 for call from DLL **REAL*8 X,P,S,NP**

Input values:

- P** - Pressure p in bar
- S** - Specific entropy s in kJ/(kg K)
- NP** - Calculation parameter for choosing H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0703991859$ bar,
 with $\rho_{\text{max}} = 44.0$ mol/l ($v_{\text{min}} = 0.0112737843$ m³/kg)
 from $t_{\text{trip}} = -259.35^\circ\text{C}$ to 126.85°C at $p \leq p_t = 0.0703991859$ bar

H₂ – Normal (NP = 1):

from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193^\circ\text{C}$ to 126.85°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:

H₂ – Normal (NP = 1): Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H₂ – 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

H₂-Para (NP = 0): $p < 0.0703991859$ bar or $p > 12.837878$ bar

H₂-Normal (NP = 1): $p < 0.0770478607$ bar or $p > 12.837878$ bar

References: [22]

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

Water and Steam

Library LibIF97

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

Library LibSBTL_IF97 Library LibSBTL_95

- Extremely fast property calculations according to the IAPWS Guideline 2015
- Spline-based Table Look-up Method (SBTL) applied to the Industrial Formulation IAPWS-IF97 and to the Scientific Formulation IAPWS-95 for Computational Fluid Dynamics and simulating non-stationary processes

Humid Combustion Gas Mixtures

Library LibHuGas

- Model: Ideal mixture of the real fluids:
 - CO₂ - Span, Wagner
 - H₂O - IAPWS-95
 - O₂ - Schmidt, Wagner
 - N₂ - Span et al.
 - Ar - Tegeler et al.
- and of the ideal gases:
 - SO₂, CO, Ne
- (Scientific Formulation of Bucker 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

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 ₂ O	F ₂	Propane
N ₂	SO ₂	NH ₃	Iso-Butane
O ₂	H ₂	Methane	n-Butane
CO	H ₂ S	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 Bucker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bucker 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 ₂ H ₆ O ₂	Ethylene glycol
C ₃ H ₈ O ₂	Propylene glycol
C ₂ H ₅ OH	Ethanol
CH ₃ OH	Methanol
C ₃ H ₈ O ₃	Glycerol
K ₂ CO ₃	Potassium carbonate
CaCl ₂	Calcium chloride
MgCl ₂	Magnesium chloride
NaCl	Sodium chloride
C ₂ H ₃ KO ₂	Potassium acetate
CHKO ₂	Potassium formate
LiCl	Lithium chloride
NH ₃	Ammonia

Formulation of the International Institute of Refrigeration (IIR 2010)

Ethanol**Library LibC2H5OH**

Formulation of
Schroeder (2012)

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

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

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 $\text{C}_{10}\text{H}_{22}$ **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 $\text{C}_3\text{H}_6\text{O}$ **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

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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

Backward Functions

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

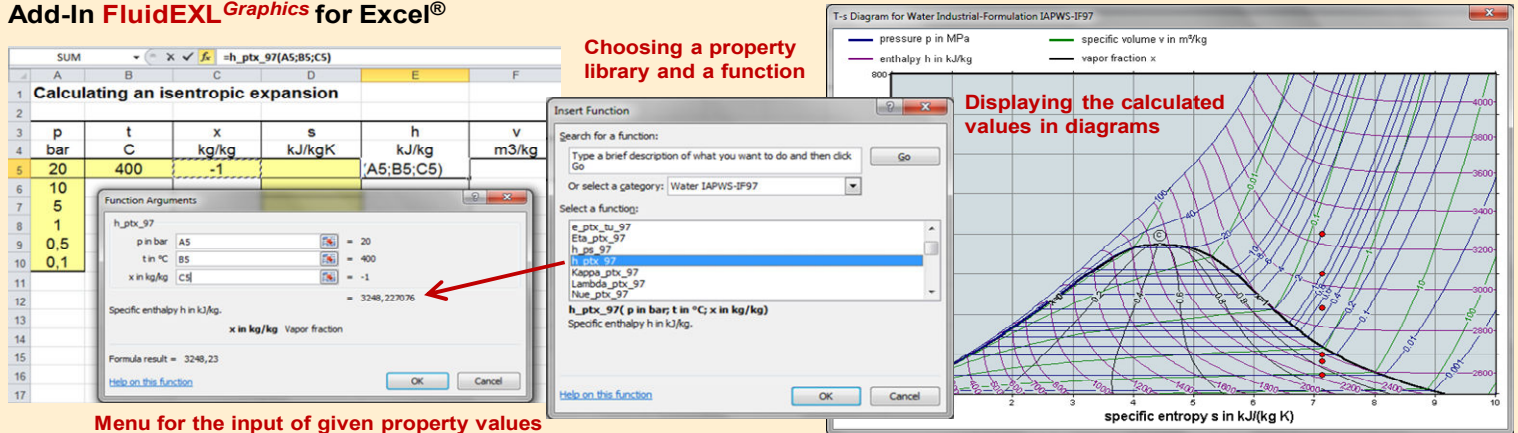
Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

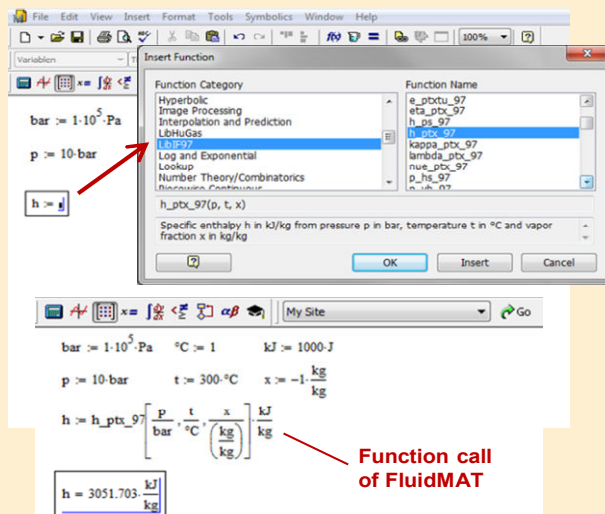
Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Add-In FluidEXL^{Graphics} for Excel[®]



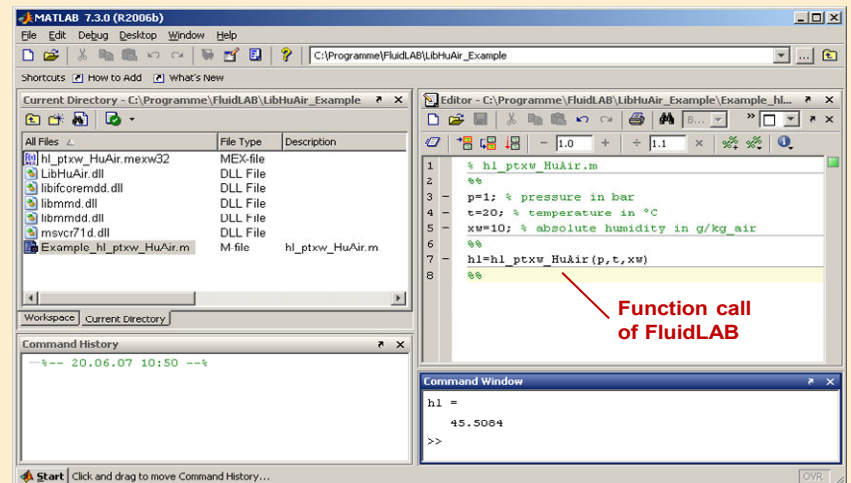
Add-In FluidMAT for Mathcad[®]

The property libraries can be used in Mathcad[®].



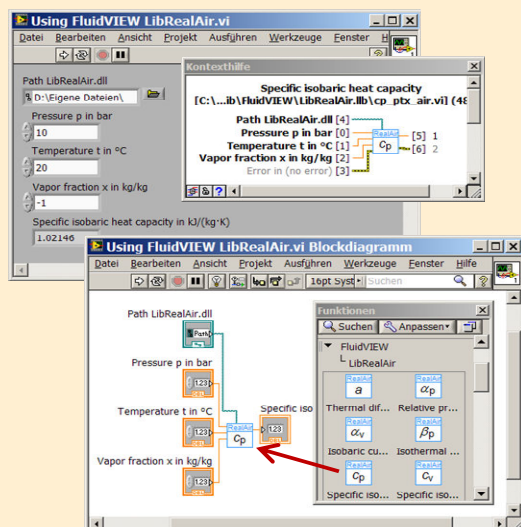
Add-In FluidLAB for MATLAB[®]

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



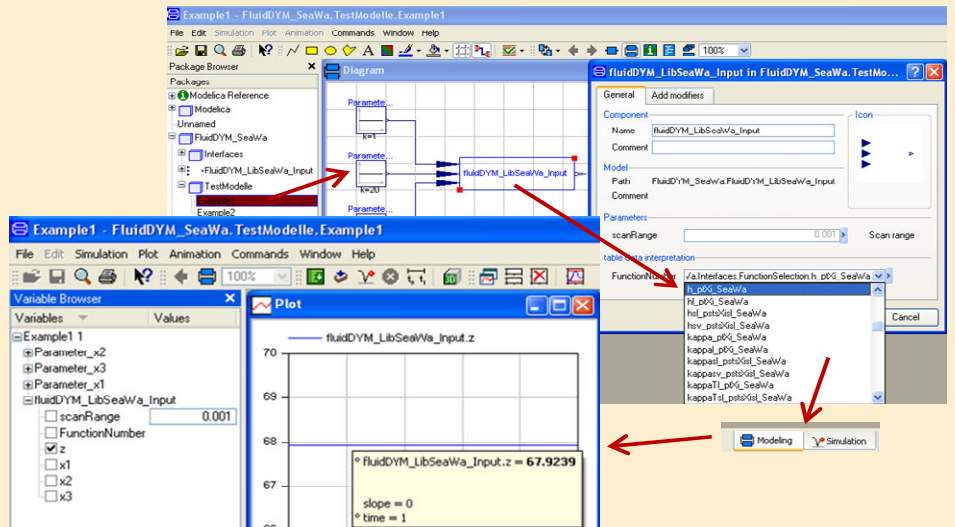
Add-On FluidVIEW for LabVIEW[™]

The property functions can be calculated in LabVIEW[™].

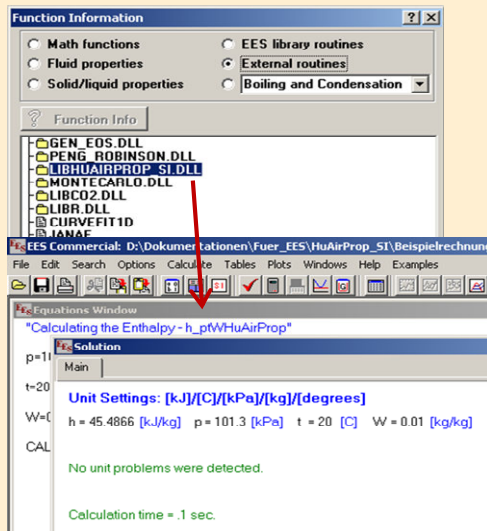


Add-In FluidDYM for DYMOLA[®] (Modelica) and SimulationX[®]

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



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



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



Online Property Calculator at www.thermofluidprop.com

Zittau's Fluid Property Calculator

Fluid:

Function:

Unit System:

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

Pressure p: bar

Temperature t: °C

Vapor fraction x: kg/kg

[Details on the vapor fraction x](#)

Calculate / Recalculate

Result:

Specific enthalpy h = kJ/kg

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

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

PDF with the [description](#)

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www.thermodynamic-property-libraries.com
www.international-steam-tables.com
www.thermodynamik-formelsammlung.de

Property Software for Pocket Calculators

FluidCasio



fx 9750 G II



CFX 9850
fx-GG20



CFX 9860 G
Graph 85



ALGEBRA
FX 2.0

FluidHP



HP 48



HP 49

FluidTI



TI Nspire CX CAS
TI Nspire CAS



TI 83
TI 84
TI 89



TI Voyage 200



TI 92

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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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

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6. Satisfied Customers

Date: 07/2019

The following companies and institutions use the property libraries:

- FluidEXL *Graphics* for Excel®
- FluidLAB for MATLAB® and Simulink
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2019

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MIBRAG, Zeitz	06/2019
Pöyry, Zürich, Switzerland	06/2019
RWTH Aachen, Inst. Strahlantriebe und Turbomaschinen	06/2019
Midiplan, Bietigheim-Bissingen	06/2019
GKS Schweinfurt	06/2019
HS Zittau/Görlitz, Wirtschaftswissenschaften und Wirtschaftsingenieurwesen	06/2019
ILK Dresden	06/2019
HZDR Helmholtz Zentrum Dresden-Rossendorf	06/2019
TH Köln, TGA	05/2019
IB Knittel, Braunschweig	05/2019
Norsk Energi, Oslo, Norway	05/2019
STEAG Essen	05/2019
Stora Enso, Eilenburg	05/2019
IB Lücke, Paderborn	05/2019
Haarslev, Sonderso, Denmark	05/2019
MAN Augsburg	05/2019
Wieland Werke, Ulm	04/2019
Fels-Werke, Elbingerode	04/2019
Univ. Luxembourg Luxembourg	04/2019
BTU Cottbus, Power Engineering	03/2009
Eins-Energie Sachsen, Schwarzenberg	03/2019
TU Dresden, Kälte- und Kryotechnik	03/2019
ITER, St. Paul Lez Durance Cedex, France	03/2019
Fraunhofer UMSICHT, Oberhausen	03/2019
Comparex Leipzig for Spedition Thiele HEMMERSBACH	03/2019
Rückert NaturGas, Lauf/Pegnitz	03/2019
BASF, Basel, Switzerland	02/2019
Stadtwerke Leipzig	02/2019

Maerz Ofenbau Zürich, Switzerland	02/2019
Hanon Systems Germany, Kerpen	02/2019
Thermofin, Heinsdorfergrund	01/2019
BSH Berlin	01/2019

2018

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

2017

Compact Kältetechnik, Dresden	12/2017
Endress + Hauser Messtechnik GmbH +Co. KG, Hannover	12/2017
TH Mittelhessen, Gießen	11/2017
Haarslev Industries, Sønderød, Denmark	11/2017
Hochschule Zittau/Görlitz, Fachgebiet Energiesystemtechnik	11/2017
ATESTEO, Alsdorf	10/2017
Wijbenga, PC Geldermalsen, Netherlands	10/2017
Fels-Werke GmbH, Elbingerode	10/2017

KIT Karlsruhe, Institute für Neutronenphysik und Reaktortechnik	09/2017
Air-Consult, Jena	09/2017
Papierfabrik Koehler, Oberkirch	09/2017
ZWILAG, Würenlingen, Switzerland	09/2017
TLK-Thermo Universität Braunschweig, Braunschweig	08/2017
Fichtner IT Consulting AG, Stuttgart	07/2017
Hochschule Ansbach, Ansbach	06/2017
RONAL, Härkingen, Switzerland	06/2017
BORSIG Service, Berlin	06/2017
BOGE Kompressoren, Bielefeld	06/2017
STEAG Energy Services, Zwingenberg	06/2017
CES clean energy solutions, Wien, Austria	04/2017
Princeton University, Princeton, USA	04/2017
B2P Bio-to-Power, Wadersloh	04/2017
TU Dresden, Institute for Energy Engineering, Dresden	04/2017
SAINT-GOBAIN, Vaujours, France	03/2017
TU Bergakademie Freiberg, Chair of Thermodynamics, Freiberg	03/2017
SCHMIDT + PARTNER, Therwil, Switzerland	03/2017
KAESER Kompressoren, Gera	03/2017
F&R, Praha, Czech Republic	03/2017
ULT Umwelt-Lufttechnik, Löbau	02/2017
JS Energie & Beratung, Erding	02/2017
Kelvion Brazed PHE, Nobitz-Wilchwitz	02/2017
MTU Aero Engines, München	02/2017
Hochschule Zittau/Görlitz, IPM	01/2017
CombTec ProCE, Zittau	01/2017
SHELL Deutschland Oil, Wesseling	01/2017
MARTEC Education Center, Frederikshaven, Denmark	01/2017
SynErgy Thermal Management, Krefeld	01/2017

2016

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

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

2015

EES Enerko, Aachen	12/2015
Rudolf IB, Strau, Austria	12/2015
Allborg University, Department of Energie, Aalborg, Denmark	12/2015
University of Lyubljana, Slovenia	12/2015
Steinbrecht IB, Berlin	11/2015
Universidad Carlos III de Madrid, Madrid, Spain	11/2015
STEAK, Essen	11/2015
Bosch, Lohmar	10/2015
Team Turbo Machines, Rouen, France	09/2015
BTC – Business Technology Consulting AG, Oldenburg	07/2015
KIT Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen	07/2015
ILK, Dresden	07/2015
Schniewindt GmbH & Co. KG, Neuenwalde	08/2015

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MTU Aero Engines AG, Munich	04/2014
GKS, Schweinfurt	03/2014
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EP-E, Niederstetten	03/2014
Rückert NatUrgas GmbH, Lauf	03/2014
YESS-World, South Korea	03/2014
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KIT-TVT, Karlsruhe	02/2014
Stadtwerke Neuburg	02/2014
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Envi-con, Nuremberg	01/2014
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Technical University of Braunschweig	01/2014
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2013

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VOITH, Kunshan, China	12/2013
ULT, Löbau	12/2013
MAN, Copenhagen, Dänemark	11/2013
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Haarslev Industries, Herlev, Dänemark	11/2013
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Ingersoll-Rand, Oberhausen	11/2013
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IAV, Chemnitz	10/2013
Technical University of Regensburg	10/2013
PD-Energy, Bitterfeld	09/2013
Thermofin, Heinsdorfergrund	09/2013
SHI, New Jersey, USA	09/2013
M&M Turbinentechnik, Bielefeld	08/2013
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TIG-Group, Husum	08/2013
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University of Budapest, Hungary	08/2013
Siemens, Frankenthal	08/2013, 10/2013

	11/2013
VGB, Essen	07/2013, 11/2013
Brunner Energieberatung, Zurich, Switzerland	07/2013
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University of Maryland, USA	07/2013, 08/2013
University of Princeton, USA	07/2013
NIST, Boulder, USA	06/2013
IGUS GmbH, Dresden	06/2013
BHR Bilfinger, Essen	06/2013
SÜDSALZ, Bad Friedrichshall	06/2013, 12/2013
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KIER, Gajeong-ro, Südkorea	05/2013
Schwing/Stetter GmbH, Memmingen	05/2013
Vattenfall, Berlin	05/2013
AUTARK, Kleinmachnow	05/2013
STEAG, Zwingenberg	05/2013
Hochtief, Düsseldorf	05/2013
University of Stuttgart	04/2013
Technical University -Bundeswehr, Munich	04/2013
Rerum Cognitio Forschungszentrum, Frankfurt	04/2013
Kältetechnik Dresden + Bremen, Alfhausen	04/2013
University Auckland, New Zealand	04/2013
MASDAR Institut, Abu Dhabi, United Arab Emirates	03/2013
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VEO, Eisenhüttenstadt	02/2013
ENTEC, Auerbach	02/2013
Caterpillar, Kiel	02/2013
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Technical University of Dusseldorf	02/2013
ILK, Dresden	01/2013, 08/2013
Fichtner IT, Stuttgart	01/2013, 11/2013
Schnepf Ingenieurbüro, Nagold	01/2013
Schütz Engineering, Wadgassen	01/2013
Endress & Hauser, Reinach, Switzerland	01/2013
Oschatz GmbH, Essen	01/2013
frischli Milchwerke, Rehburg-Loccum	01/2013

2012

Voith, Bayreuth	12/2012
Technical University of Munich	12/2012
Dillinger Huette	12/2012
University of Stuttgart	11/2012
Siemens, Muehlheim	11/2012
Sennheiser, Hannover	11/2012
Oschatz GmbH, Essen	10/2012
Fichtner IT, Stuttgart	10/2012, 11/2012
Helbling Technik AG, Zurich, Switzerland	10/2012
University of Duisburg	10/2012

Rerum Cognitio Forschungszentrum, Frankfurt	09/2012
Pöyry Deutschland GmbH, Dresden	08/2012
Extracciones, Guatemala	08/2012
RWE, Essen	08/2012
Weghaus Consulting Engineers, Wuerzburg	08/2012
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GEA, Nobitz	07/2012
Meyer Werft, Papenburg	07/2012
STEAG, Herne	07/2012
GRS, Cologne	06/2012
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Siemens, Freiburg	06/2012
Nikon Research of America, Belmont, USA	06/2012
Niederrhein University of Applied Sciences, Krefeld	06/2012
STEAG, Zwingenberg	06/2012
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SPX Balcke-Dürr, Ratingen	05/2012, 07/2012
Gruber-Schmidt, Wien, Austria	04/2012
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ALSTOM, Baden	04/2012
SKW, Piesteritz	04/2012
TERA Ingegneria, Trento, Italy	04/2012
Siemens, Erlangen	04/2012, 05/2012
LAWI Power, Dresden	04/2012
Stadtwerke Leipzig	04/2012
SEITZ, Wetzikon, Switzerland	03/2012, 07/2012
M & M, Bielefeld	03/2012
Sennheiser, Wedemark	03/2012
SPG, Montreuil Cedex, France	02/2012
German Destillation, Sprendlingen	02/2012
Lopez, Munguia, Spain	02/2012
Endress & Hauser, Hannover	02/2012
Palo Alto Research Center, USA	02/2012
WIPAK, Walsrode	02/2012
Freudenberg, Weinheim	01/2012
Fichtner, Stuttgart	01/2012
airinotec, Bayreuth	01/2012, 07/2012
University Auckland, New Zealand	01/2012
VPC, Vetschau	01/2012
Franken Guss, Kitzingen	01/2012

2011

XRG-Simulation, Hamburg	12/2011
Smurfit Kappa PPT, AX Roermond, Netherlands	12/2011
AWTEC, Zurich, Switzerland	12/2011
eins-energie, Bad Elster	12/2011
BeNow, Rodenbach	11/2011
Luzern University of Applied Sciences, Switzerland	11/2011
GMVA, Oberhausen	11/2011
CCI, Karlsruhe	10/2011
W.-Büchner University of Applied Sciences, Pfungstadt	10/2011
PLANAIR, La Sagne, Switzerland	10/2011
LAWI, Dresden	10/2011
Lopez, Munguia, Spain	10/2011
University of KwaZulu-Natal, Westville, South Africa	10/2011
Voith, Heidenheim	09/2011
SpgBe Montreal, Canada	09/2011
SPG TECH, Montreuil Cedex, France	09/2011
Voith, Heidenheim-Mergelstetten	09/2011
MTU Aero Engines, Munich	08/2011
MIBRAG, Zeitz	08/2011
RWE, Essen	07/2011
Fels, Elingerode	07/2011
Weihenstephan University of Applied Sciences	07/2011, 09/2011
	10/2011
Forschungszentrum Juelich	07/2011
RWTH Aachen University	07/2011, 08/2011
INNEO Solutions, Ellwangen	06/2011
Caliqua, Basel, Switzerland	06/2011
Technical University of Freiberg	06/2011
Fichtner IT Consulting, Stuttgart	05/2011, 06/2011,
	08/2011
Salzgitter Flachstahl, Salzgitter	05/2011
Helbling Beratung & Bauplanung, Zurich, Switzerland	05/2011
INEOS, Cologne	04/2011
Enseleit Consulting Engineers, Siebigerode	04/2011
Witt Consulting Engineers, Stade	03/2011
Helbling, Zurich, Switzerland	03/2011
MAN Diesel, Copenhagen, Denmark	03/2011
AGO, Kulmbach	03/2011
University of Duisburg	03/2011, 06/2011
CCP, Marburg	03/2011
BASF, Ludwigshafen	02/2011
ALSTOM Power, Baden, Switzerland	02/2011
Universität der Bundeswehr, Munich	02/2011
Calorifer, Elgg, Switzerland	01/2011
STRABAG, Vienna, Austria	01/2011
TUEV Sued, Munich	01/2011

ILK Dresden
 Technical University of Dresden

01/2011
 01/2011, 05/2011
 06/2011, 08/2011

2010

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

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

2009

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

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

2008

Pink, Langenwang	01/2008
Fischer-Uhrig, Berlin	01/2008
University of Karlsruhe	01/2008
MAAG, Kuesnacht, Switzerland	02/2008
M&M Turbine Technology, Bielefeld	02/2008
Lentjes, Ratingen	03/2008
Siemens Power Generation, Goerlitz	04/2008
Evonik, Zwingenberg (general EBSILON program license)	04/2008
WEBASTO, Neubrandenburg	04/2008
CFC Solutions, Munich	04/2008
RWE IT, Essen	04/2008
Rerum Cognitio, Zwickau	04/2008, 05/2008
ARUP, Berlin	05/2008
Research Center, Karlsruhe	07/2008
AWECO, Neukirch	07/2008
Technical University of Dresden, Professorship of Building Services	07/2008
Technical University of Cottbus, Chair in Power Plant Engineering	07/2008, 10/2008
Ingersoll-Rand, Unicov, Czech Republic	08/2008
Technip Benelux BV, Zoetermeer, Netherlands	08/2008
Fennovoima Oy, Helsinki, Finland	08/2008
Fichtner Consulting & IT, Stuttgart	09/2008
PEU, Espenhain	09/2008
Poyry, Dresden	09/2008
WINGAS, Kassel	09/2008
TUEV Sued, Dresden	10/2008
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	10/2008, 11/2008
AWTEC, Zurich, Switzerland	11/2008
Siemens Power Generation, Erlangen	12/2008

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Audi, Ingolstadt	02/2007
ANO Abfallbehandlung Nord, Bremen	02/2007
TUEV NORD SysTec, Hamburg	02/2007
VER, Dresden	02/2007
Technical University of Dresden, Chair in Jet Propulsion Systems	02/2007
Redacom, Nidau, Switzerland	02/2007
Universität der Bundeswehr, Munich	02/2007
Maxxtec, Sinsheim	03/2007
University of Rostock, Chair in Technical Thermodynamics	03/2007
AGO, Kulmbach	03/2007
University of Stuttgart, Chair in Aviation Propulsions	03/2007
Siemens Power Generation, Duisburg	03/2007
ENTHAL Haustechnik, Rees	05/2007
AWECO, Neukirch	05/2007
ALSTOM, Rugby, Great Britain	06/2007
SAAS, Possendorf	06/2007
Grenzebach BSH, Bad Hersfeld	06/2007
Reichel Engineering, Haan	06/2007
Technical University of Cottbus, Chair in Power Plant Engineering	06/2007
Voith Paper Air Systems, Bayreuth	06/2007
Egger Holzwerkstoffe, Wismar	06/2007
Tissue Europe Technologie, Mannheim	06/2007
Dometic, Siegen	07/2007
RWTH Aachen University, Institute for Electrophysics	09/2007
National Energy Technology Laboratory, Pittsburg, USA	10/2007
Energieversorgung Halle	10/2007
AL-KO, Jettingen	10/2007
Grenzebach BSH, Bad Hersfeld	10/2007
Wiesbaden University of Applied Sciences, Department of Engineering Sciences	10/2007
Endress+Hauser Messtechnik, Hannover	11/2007
Munich University of Applied Sciences, Department of Mechanical Engineering	11/2007
Rerum Cognitio, Zwickau	12/2007
Siemens Power Generation, Erlangen	11/2007
University of Rostock, Chair in Technical Thermodynamics	11/2007, 12/2007

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STORA ENSO Sachsen, Eilenburg	01/2006
Technical University of Munich, Chair in Energy Systems	01/2006
NUTEC Engineering, Bisikon, Switzerland	01/2006, 04/2006
Conwel eco, Bochov, Czech Republic	01/2006
Offenburg University of Applied Sciences	01/2006
KOCH Transporttechnik, Wadgassen	01/2006
BEG Bremerhavener Entsorgungsgesellschaft	02/2006
Deggendorf University of Applied Sciences, Department of Mechanical Engineering and Mechatronics	02/2006
University of Stuttgart,	02/2006

Department of Thermal Fluid Flow Engines	
Technical University of Munich,	02/2006
Chair in Apparatus and Plant Engineering	
Energietechnik Leipzig (company license),	02/2006
Siemens Power Generation, Erlangen	02/2006, 03/2006
RWE Power, Essen	03/2006
WAETAS, Poberschau	04/2006
Siemens Power Generation, Goerlitz	04/2006
Technical University of Braunschweig,	04/2006
Department of Thermodynamics	
EnviCon & Plant Engineering, Nuremberg	04/2006
Brassel Engineering, Dresden	05/2006
University of Halle-Merseburg,	05/2006
Department of USET Merseburg incorporated society	
Technical University of Dresden,	05/2006
Professorship of Thermic Energy Machines and Plants	
Fichtner Consulting & IT Stuttgart	05/2006
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M&M Turbine Technology, Bielefeld	06/2006
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ThyssenKrupp Marine Systems, Kiel	07/2006
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Konstanz University of Applied Sciences,	10/2006
Course of Studies Construction and Development	
Siemens Power Generation, Duisburg	10/2006
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Department of Mechanical Engineering	
Siemens Power Generation, Berlin	11/2006
Zikesch Armaturentechnik, Essen	11/2006
Wismar University of Applied Sciences, Seafaring Department	11/2006
BASF, Schwarzheide	12/2006
Enertech Energie und Technik, Radebeul	12/2006

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TUEV Nord, Hannover	01/2005
J.H.K Plant Engineering and Service, Bremerhaven	01/2005
Electrowatt-EKONO, Zurich, Switzerland	01/2005
FCIT, Stuttgart	01/2005
Energietechnik Leipzig (company license)	02/2005, 04/2005
	07/2005
eta Energieberatung, Pfaffenhofen	02/2005
FZR Forschungszentrum, Rossendorf/Dresden	04/2005
University of Saarbruecken	04/2005
Technical University of Dresden	04/2005
Professorship of Thermic Energy Machines and Plants	
Grenzebach BSH, Bad Hersfeld	04/2005
TUEV Nord, Hamburg	04/2005

Technical University of Dresden, Waste Management	05/2005
Siemens Power Generation, Goerlitz	05/2005
Duesseldorf University of Applied Sciences, Department of Mechanical Engineering and Process Engineering	05/2005
Redacom, Nidau, Switzerland	06/2005
Dumas Verfahrenstechnik, Hofheim	06/2005
Alensys Engineering, Erkner	07/2005
Stadtwerke Leipzig	07/2005
SaarEnergie, Saarbruecken	07/2005
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Technical University of Cottbus, Chair in Power Plant Engineering	08/2005
Vattenfall Europe, Berlin (group license)	08/2005
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Basel University of Applied Sciences, Department of Mechanical Engineering, Switzerland	10/2005
Midiplan, Bietigheim-Bissingen	11/2005
Technical University of Freiberg, Chair in Hydrogeology	11/2005
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Visteon, Kerpen	03/2004, 10/2004
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Rerum Cognitio, Zwickau	04/2004
University of Saarbruecken	04/2004
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HEW-Kraftwerk, Tiefstack	06/2004
h s energieanlagen, Freising	07/2004
FCIT, Stuttgart	08/2004
Physikalisch Technische Bundesanstalt (PTB), Braunschweig	08/2004
Mainova Frankfurt	08/2004
Rietschle Energieplaner, Winterthur, Switzerland	08/2004
MAN Turbo Machines, Oberhausen	09/2004
TUEV Sued, Dresden	10/2004
STEAG Kraftwerk, Herne	10/2004, 12/2004
University of Weimar	10/2004
energeticals (e-concept), Munich	11/2004
SorTech, Halle	11/2004

Enertech EUT, Radebeul (company license)	11/2004
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2003

Paper Factory, Utzenstorf, Switzerland	01/2003
MAB Plant Engineering, Vienna, Austria	01/2003
Wulff Energy Systems, Husum	01/2003
Technip Benelux BV, Zoetermeer, Netherlands	01/2003
ALSTOM Power, Baden, Switzerland	01/2003, 07/2003
VER, Dresden	02/2003
Rietschle Energieplaner, Winterthur, Switzerland	02/2003
DLR, Leupholdhausen	04/2003
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Pettersson+Ahrends, Ober-Moerlen	05/2003
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Atlas-Stord, Rodovre, Denmark	08/2003
ENERKO, Aldenhoven	08/2003
STEAG RKB, Leuna	08/2003
eta Energieberatung, Pfaffenhofen	08/2003
exergie, Dresden	09/2003
AWTEC, Zurich, Switzerland	09/2003
Energie, Timelkam, Austria	09/2003
Electrowatt-EKONO, Zurich, Switzerland	09/2003
LG, Annaberg-Buchholz	10/2003
FZR Forschungszentrum, Rossendorf/Dresden	10/2003
EnviCon & Plant Engineering, Nuremberg	11/2003
Visteon, Kerpen	11/2003
VEO Vulkan Energiewirtschaft Oderbruecke, Eisenhuettenstadt	11/2003
Stadtwerke Hannover	11/2003
SaarEnergie, Saarbruecken	11/2003
Fraunhofer-Gesellschaft, Munich	12/2003
Erfurt University of Applied Sciences, Department of Supply Engineering	12/2003
SorTech, Freiburg	12/2003
Mainova, Frankfurt	12/2003
Energieversorgung Halle	12/2003

2002

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VEAG, Berlin (group license)	12/2002

2001

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Eco Design, Saitamaken, Japan	01/2001
M&M Turbine Technology, Bielefeld	01/2001, 09/2001
MVV Energie, Mannheim	02/2001
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PREUSSAG NOELL, Wuerzburg	03/2001
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h s energieanlagen, Freising	09/2001
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DVO Data Processing Service, Oberhausen	05/2000
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VAUP Process Automation, Landau	08/2000
Knuerr-Lommatec, Lommatzsch	09/2000
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Compania Electrica, Bogota, Colombia	10/2000
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Technical University of Graz, Department of Thermal Engineering, Austria	11/1999
Ostendorf Engineering, Gummersbach	12/1999

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B+H Software Engineering Stuttgart	08/1998
Alfa Engineering, Switzerland	09/1998
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SCA Hygiene Products, Munich	10/1998
RWE Energie, Neurath	10/1998
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BASF, Ludwigshafen (group license)	11/1998
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Gerb, Dresden	06/1997
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