Property Library for Hydrogen

FluidPRIME
with LibH2
for Mathcad Prime®

Prof. Hans-Joachim Kretzschmar
Matthias Kunick
S. Herrmann
M. Sünder

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LibH2

FluidPRIME for Mathcad Prime®

Contents

Prof. Dr. Hans-Joachim Kretzschmar
Wallotstr. 3, 01307 Dresden, Germany
Phone: +49-351-27597860
Mobile: +49-172-7914607
Fax: +49-3222-4262250
Email: info@thermofluidprop.com
Internet: www.thermofluidprop.com

0. Package Contents

Zip file "CD_FluidPRIME_LibH2.zip" includes the following files:

FluidPRIME_LibH2_Docu.pdf	- User's Guide
Functions_LibH2.mcdx	- Mathcad Prime® worksheet with all functions
LibH2.msi	- MSI installer
setup.exe	- Setup installer
LibH2.dll	- DLL with functions of the LibH2 library

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	APTXH2(P,T,X,NP)	C_APTXH2(A,P,T,X,NP)	Thermal diffusivity	m^2/s
c_p = f(p,t,x,NP)	cp_ptx_H2	CPPTXH2(P,T,X,NP)	C_CPPTXH2(CP,P,T,X,NP)	Specific isobaric heat capacity	kJ/(kg K)
c_v = f(p,t,x,NP)	cp_ptx_H2	CVPTXH2(P,T,X,NP)	C_CVPTXH2(CV,P,T,X,NP)	Specific isochoric heat capacity	kJ/(kg K)
η = f(p,t,x,NP)	eta_ptx_H2	ETAPTXH2(P,T,X,NP)	C_ETAPTXH2(ETA,P,T,X,NP)	Dynamic viscosity	Pa s
h = f(p,t,x,NP)	h_ptx_H2	HPTXH2(P,T,X,NP)	C_HPTXH2(H,P,T,X,NP)	Specific enthalpy	kJ/kg
κ = f(p,t,x,NP)	kappa_ptx_H2	KAPPTXH2(P,T,X,NP)	C_KAPPTXH2(KAP,P,T,X,NP)	Isentropic exponent	-
λ = f(p,t,x,NP)	lambda_ptx_H2	LAMPTXH2(P,T,X,NP)	C_LAMPTXH2(LAM,P,T,X,NP)	Thermal conductivity	W/(m K)
ν = f(p,t,x,NP)	ny_ptx_H2	NYPTXH2(P,T,X,NP)	C_NYPTXH2(NY,P,T,X,NP)	Kinematic viscosity	m^2/s
p_{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	PRPTXH2(P,T,X,NP)	C_PRPTXH2(PR,P,T,X,NP)	*Prandtl*-Number	-
ρ = f(p,t,x,NP)	rho_ptx_H2	RHOPTXH2(P,T,X,NP)	C_RHOPTXH2(RHO,P,T,X,NP)	Density	kg/m^3
s = f(p,t,x,NP)	s_ptx_H2	SPTXH2(P,T,X,NP)	C_SPTXH2(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_{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	UPTXH2(P,T,X,NP)	C_UPTXH2(U,P,T,X,NP)	Internal energy	kJ/kg
v = f(p,t,x,NP)	v_ptx_H2	VPTXH2(P,T,X,NP)	C_VPTXH2(V,P,T,X,NP)	Specific volume	m^3/kg
w = f(p,t,x,NP)	w_ptx_H2	WPTXH2(P,T,X,NP)	C_WPTXH2(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 H_2-Normal and H_2-Para. The form is specified by the parameter NP.

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

NP = 0, for H_2-Para.

Details on the vapor fraction *x*

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

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

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

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

Wet steam region:

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

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

Range of validity

Temperature range:

H_2-Para (NP = 0):

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

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

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

H_2-Normal (NP = 1):

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

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

from t_{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 H_2-Normal und H_2-Para is based upon the following approximations:

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

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

Reference state

h = 0 and s = 0

at p = 1.01325 bar

and t = - 252.8731 °C

Hint!

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

2 Application of FluidPRIME in Mathcad Prime®

FluidPRIME has been developed to calculate thermodynamic properties in Mathcad Prime® more conveniently. Within Mathcad Prime, it enables the direct call of functions relating to humid air from the LibH2 property library.

2.1 Installing FluidPRIME

In this section, the installation of FluidPRIME LibH2 is described.
After you have downloaded and extracted the zip-file "CD_FluidPRIME_LibH2.zip", you will see the folder

CD_FluidPRIME_LibH2

in your Windows Explorer, Norton Commander etc.

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

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

FluidPRIME_LibH2_Docu.pdf
Functions_LibH2.mcdx
LibH2.msi
setup.exe
LibH2.dll

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

setup.exe.

Note: If you get an error message during the installation, please try the LibH2.msi instead of the setup.exe for the installation. The steps trough the install assistent are similiary on both the .exe and the .msi file.

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

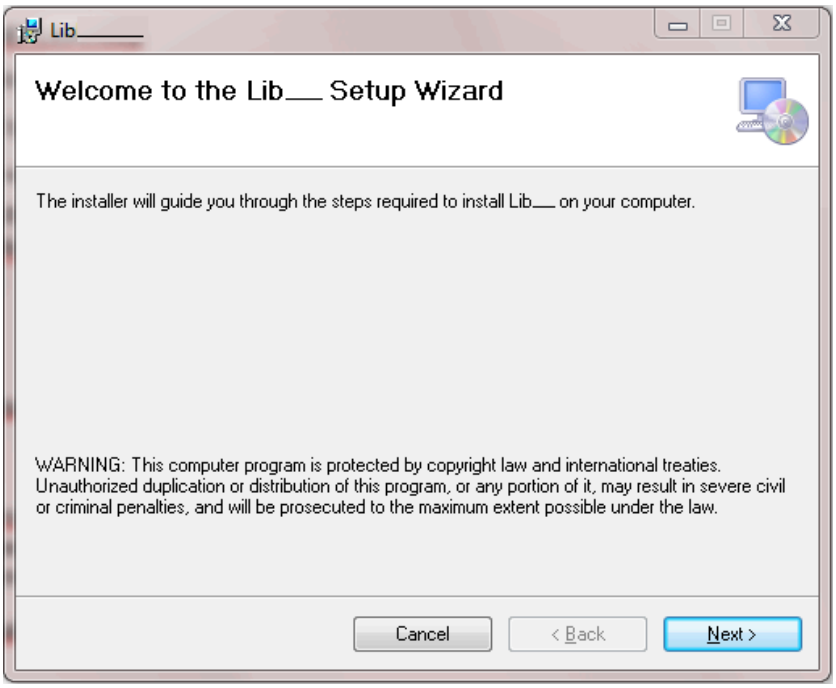


Figure 2.1: Setup Wizard

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

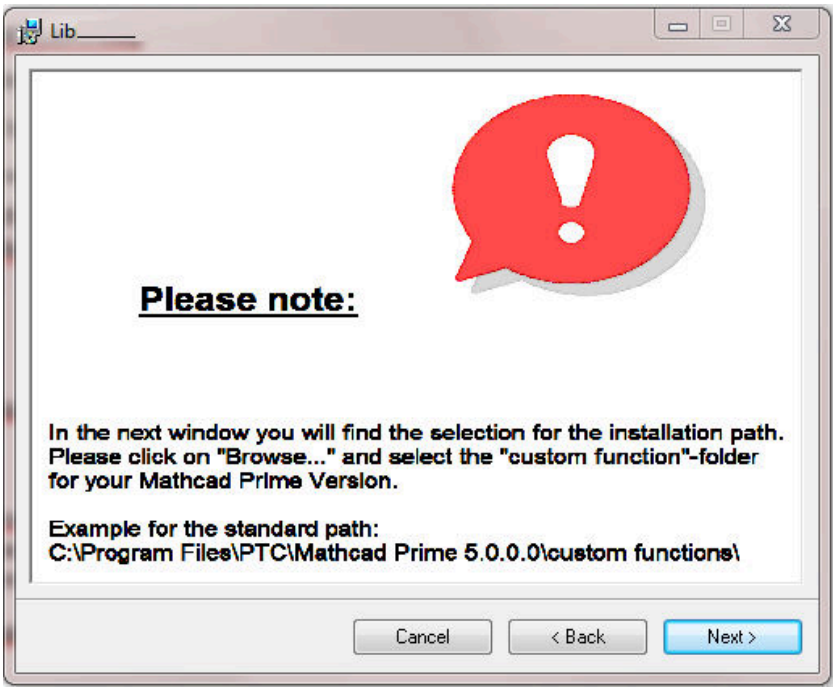


Figure 2.2: Note Window

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

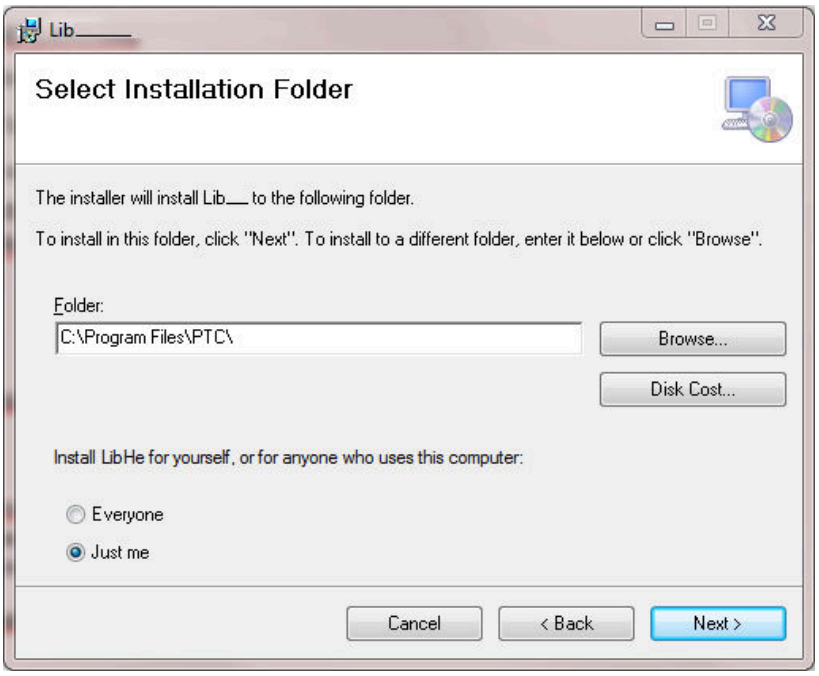


Figure 2.3: Select Installation Folder

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

You will get the standard path:

C:\Program Files\PTC\

Now select your Mathcad Prime® version folder. For example

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

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

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

that you can also see in Figure 2.4.

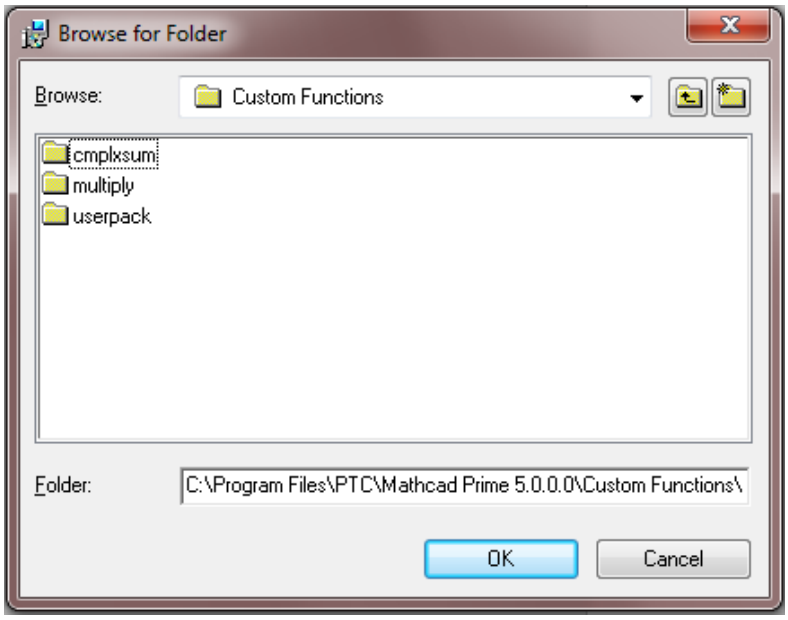


Figure 2.4: "Browse for Folder"-window with the full installation path

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

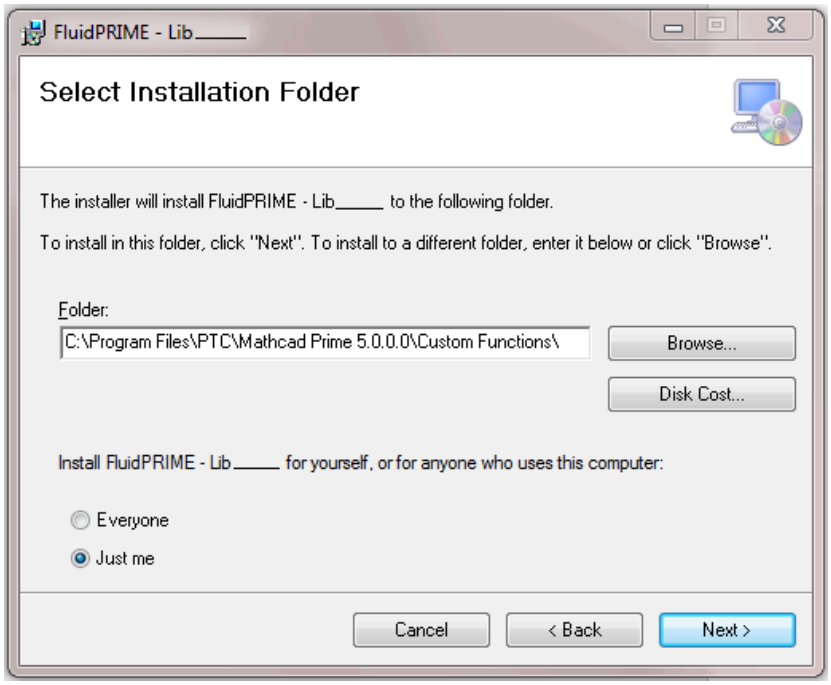


Figure 2.5: "Select Installation Folder"-window

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

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

The installation of FluidPRIME with the library LibH2 is finished.

Finally, please copy or overwrite the LibH2.dll-file in the installation folder that is described before, with the file in the zip-file.

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

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

LC.dll	LibH2.dll	PRIME_LibH2.dll
libifcoremd.dll	libiomp5.dll	libmmd.dll.

Note:

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

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

2.2 Licensing the LibH2 Property Library

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

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

Now we will calculate, step by step, the specific enthalpy *h* as a function of pressure *p*, temperature *t* and vapor fraction *x* for water and steam from the Industrial Formulation IAPWS-H2, using FluidPRIME.

- Start Mathcad Prime.
- Type "p:" and enter the value for the pressure *p* in bar.
  (Range of validity of the H2: from 0.001 bar to 1210 bar)
  e. g.: Enter "p:10" for the first operand
- Type "t:" and enter the value for the temperature *t* in °C.
  (Range of validity of the H2: (Range of validity: t = t_{mel} or t_{min} ... 126.85°C)
  e. g.: Enter "t:50" for the second operand
- 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* <u>and</u> p = –1, or the given value for *p* <u>and</u> t = –1, plus the value for *x* between 0 and 1.
  However, if *p* <u>and</u> *t* <u>and</u> *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 H_2-Para:

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

  Vapor pressure curve of H_2-Normal:

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

  e. g.: Enter "x:-1" for the third operand
- Confirm your entry by pressing the "ENTER" key.
- Your Mathcad Prime calculation window should look like Figure 2.3:

$p := 10$
$t := 50$
$x := -1$
$NP := 1$

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

- Now, type open the file Functions_LibH2.mcdx. In this Mathcad Prime® worksheet you can find all the functions of the library
- Search the function h_ptx_H2(, ,) and mark it by drag a selection rectangle around it.
- Copy the marked function and paste it into your example worksheet
- Click it the function and type "h:" in front of it.
- Your Mathcad Prime calculation window should look like Figure 2.4:

$p := 10$
$t := 50$
$x := -1$
$NP := 1$

$h := h\_ptx\_H2(\square, \square, \square, \square)$

Figure 2.4: Example Mathcad Prime® sheet i

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

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

  You will now see the result h=4.295 x 10^3. The corresponding unit is kJ/kg (see table of the property functions in Chapter 1).

In the next figure you can see the calculated value.

$p := 10$

$t := 50$

$x := -1$

$NP := 1$

$h := \text{h\_ptx\_H2}(p, t, x, NP)$

$h = 4.295 \cdot 10^3$

Figure 2.5: Example Mathcad Prime® sheet with finished calculation

2.4 Removing FluidPRIME

To remove FluidPRIME with the library LibH2 from your hard drive, carry out the following steps:

- Click "Start" in the lower task bar of your desktop, then "Settings" and then "Control Panel".
- Now, double click on "Add or Remove Programs".
- In the list box of the "Add or Remove Programs" window that appears select "FluidPRIME - LibH2" by clicking on it and click the "Add/Remove…" button.
- In the following dialog box click "Yes" and wait until the windows is closing.
- Finally, close the "Add or Remove Programs" and "Control Panel" windows.

Now FluidPRIME with the library 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Temperature range:

H_2 – Para (NP = 0):

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

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

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

H_2 – Normal (NP = 1):

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

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

from $t_{trip} = -259.193$°C to 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* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* between 0 and 1. When calculating wet steam and *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

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

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

Results for wrong input values

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

H_2-Normal (NP = 1):

Single phase region:
(x = - 1)

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

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

H_2-Para (NP = 0):

Single phase region:
(x = - 1)

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

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

References: [22], [23]

Specific Isobaric Heat Capacity $c_p = f(p, t, x, \mathrm{NP})$

Function Name:	**cp_ptx_H2**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION CPPTXH2(P,T,X,NP)** REAL*8 P,T,X,NP
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_CPPTXH2(CP,P,T,X,NP)** 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 H_2 – Normal or H_2 – Para

Result

CPPTXH2, CP or cp_ptx_H2 – specific isobaric heat capacity c_p in $\mathrm{kJ/(kg\ K)}$

Range of validity

Temperature range:

H_2 – Para $(\mathrm{NP} = 0)$:

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

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

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

H_2 – Normal $(\mathrm{NP} = 1)$:

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

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

from $t_{\mathrm{trip}} = -259.193$°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 <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

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

Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

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

Results for wrong input values

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

H_2-Normal (NP = 1):

Single phase region:
(x = - 1)

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

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

H_2-Para (NP = 0):

Single phase region:
(x = - 1)

p > 1210 bar or p < 0.001 bar or
t > 126.85 °C or $t < t_{mel}(p)$ or $t < t(p, \rho_{max})$ at $p \geq p_t$ = 0.0703991859 bar or
$t < t_{trip}$ = – 259.35 °C at $p < p_t$ = 0.0703991859 bar
ρ_{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: for call from Fortran	**REAL*8 FUNCTION CVPTXH2(P,T,X,NP)** REAL*8 P,T,X,NP
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_CVPTXH2(CV,P,T,X,NP)** 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Temperature range:

H_2 – Para (NP = 0):

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

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

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

H_2 – Normal (NP = 1):

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

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

from $t_{trip} = -259.193$°C to 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 <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

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

Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

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

Results for wrong input values

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

H_2-Normal (NP = 1):

Single phase region:
(x = - 1)

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

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

H_2-Para (NP = 0):

Single phase region:
(x = - 1)

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

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

References: [22]

Dynamic Viscosity η = f(p, t, x, NP)

Function Name:	**eta_ptx_H2**
Subroutine with function value: 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Temperature range:

H_2 – Para (NP = 0):

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

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

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

H_2 – Normal (NP = 1):

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

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

from $t_{trip} = -259.193$°C to 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 <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

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

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

Results for wrong input values

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

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

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

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

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

Boiling or dew curve:

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

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

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

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

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

Boiling or dew curve:

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

References: [22], [23]

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

Function Name:	**h_ptx_H2**
Subroutine with function value: 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Temperature range:

H_2 – Para (NP = 0):

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

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

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

H_2 – Normal (NP = 1):

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

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

from $t_{trip} = -259.193$°C to 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* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* between 0 and 1. When calculating wet steam and *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

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

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

Results for wrong input values

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

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

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

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

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

Boiling or dew curve:

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

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

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

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

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

Boiling or dew curve:

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

References: [22]

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

Function Name:	**kappa_ptx_H2**
Subroutine with function value: 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Temperature range:

H_2 – Para $(NP = 0)$:

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

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

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

H_2 – Normal $(NP = 1)$:

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

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

from $t_{trip} = -259.193$°C to 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 <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

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

Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

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

Results for wrong input values

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

H_2-Normal (NP = 1):

Single phase region:
(x = - 1)

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

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

H_2-Para (NP = 0):

Single phase region:
(x = - 1)

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

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

References: [22]

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

Function Name:	**lambda_ptx_H2**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION LAMPTH2(P,T,X,NP)** REAL*8 P,T,X,NP
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_LAMPTXH2(LAM,P,T,X,NP)** 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Temperature range:

H_2 – Para $(NP = 0)$:

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

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

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

H_2 – Normal $(NP = 1)$:

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

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

from $t_{trip} = -259.193$°C to 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 <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

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

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

Results for wrong input values

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

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

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

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

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

Boiling or dew curve:

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

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

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

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

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

Boiling or dew curve:

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

References: [22], [23]

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

Function Name:	**ny_ptx_H2**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION NYPTXH2(P,T,X,NP)** REAL*8 P,T,X,NP
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_NYPTXH2(NY,P,T,X,NP)** 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Temperature range:

H_2 – Para $(NP = 0)$:

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

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

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

H_2 – Normal $(NP = 1)$:

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

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

from $t_{trip} = -259.193$°C to 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 <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

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

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

Results for wrong input values

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

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

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

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

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

Boiling or dew curve:

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

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

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

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

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

Boiling or dew curve:

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

References: [22], [23]

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

Function Name:	**pmel_t_H2**
Subroutine with function value: 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

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

Results for wrong input values

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

$NP \neq 0$

$t <$ - 259.35 °C or $t >$ - 240.212 °C

References: [22]

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

Function Name:	**Pr_ptx_H2**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION PRPTXH2(P,T,X,NP)** REAL*8 P,T,X,NP
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_PRPTXH2(PR,P,T,X,NP)** 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Temperature range:

H_2 – Para (NP = 0):

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

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

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

H_2 – Normal (NP = 1):

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

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

from $t_{trip} = -259.193$°C to 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* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* between 0 and 1. When calculating wet steam and *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

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

Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

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

Results for wrong input values

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

H_2-Normal (NP = 1):

Single phase region:
(x = - 1)

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

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

H_2-Para (NP = 0):

Single phase region:
(x = - 1)

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

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

References: [22]

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

Function Name:	**ps_t_H2**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION PSTH2(T,NP)** REAL*8 T,NP
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_PSTH2(PS,T,NP)** REAL*8 PS,T,NP

Input values:

T - Temperature t in °C

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

Result

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

Range of validity

Temperature range:

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

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

Results for wrong input values

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

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

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

References: [22], [23]

Density ρ = f(p, t, x, NP)

Function Name:	**rho_ptx_H2**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION RHOPTXH2(P,T,X,NP)** REAL*8 P,T,X,NP
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_RHOPTXH2(RHO,P,T,X,NP)** 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Temperature range:

H_2 – Para (NP = 0):

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

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

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

H_2 – Normal (NP = 1):

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

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

from $t_{trip} = -259.193$°C to 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 <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

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

Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

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

Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

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

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

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

Boiling or dew curve:

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

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

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

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

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

Boiling or dew curve:

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

References: [22]

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

Function Name:	**s_ptx_H2**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION SPTXH2(P,T,X,NP)** REAL*8 P,T,X,NP
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_SPTXH2(S,P,T,X,NP)** 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Temperature range:

H_2 – Para (NP = 0):

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

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

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

H_2 – Normal (NP = 1):

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

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

from $t_{trip} = -259.193$°C to 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* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* between 0 and 1. When calculating wet steam and *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

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

Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

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

Results for wrong input values

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

H_2-Normal (NP = 1):

Single phase region:
(x = - 1)

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

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

H_2-Para (NP = 0):

Single phase region:
(x = - 1)

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

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

References: [22]

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

Function Name:	**t_ph_H2**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION TPHH2(P,H,NP)** REAL*8 P,H,NP
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_TPHH2(T,P,H,NP)** 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Temperature range:

H_2 – Para $(NP = 0)$:

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

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

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

H_2 – Normal $(NP = 1)$:

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

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

from $t_{trip} = -259.193$°C to 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:

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

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

Results for wrong input values

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

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

at the calculation result t > 126.85 °C or

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

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

Boiling or dew curve:

at p > 12.837878 bar or p < 0.0770478607 bar or
calculation result t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

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

Boiling or dew curve:

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

References: [22]

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

Function Name:	**t_ps_H2**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION TPSH2(P,S,NP)** REAL*8 P,S,NP
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_TPSH2(T,P,S,NP)** 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Temperature range:

H_2 – Para (NP = 0):

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

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

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

H_2 – Normal (NP = 1):

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

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

from $t_{trip} = -259.193$°C to 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:

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

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

Results for wrong input values

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

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

at the calculation result t > 126.85 °C or

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

$t < t_{trip} = -$ 259.193 °C at $p < p_t =$ 0.0770478607 bar ($\rho_{max} =$ 38.148mol/l)

Boiling or dew curve:

at p > 12.837878 bar or p < 0.0770478607 bar or
calculation result t > - 240.212 °C or t < - 259.193 °C

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or
at the calculation result t > 126.85 °C or

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

$t < t_{trip} = -$ 259.35 °C at $p < p_t =$ 0.0703991859 bar ($\rho_{max} =$ 44.0 mol/l)

Boiling or dew curve:

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

References: [22]

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

Function Name:	**ts_p_H2**
Subroutine with function value: 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Pressure range:

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

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

Results for wrong input values

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

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

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

References: [22], [23]

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

Function Name:	**tmel_p_H2**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION TMELH2(P,NP)** REAL*8 P,NP
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_TMELH2(TMEL,P,NP)** REAL*8 TMEL,P,NP

Input values:

P - Pressure p in bar

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

Result

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

Range of validity

Pressure range: from 0.0703991859 bar to 1210 bar

Results for wrong input values

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

$NP \neq 0$

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

References: [22]

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

Function Name:	**u_ptx_H2**
Subroutine with function value: 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Temperature range:

H_2 – Para (NP = 0):

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

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

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

H_2 – Normal (NP = 1):

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

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

from $t_{trip} = -259.193$°C to 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* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* between 0 and 1. When calculating wet steam and *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

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

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

Results for wrong input values

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

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

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

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

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

Boiling or dew curve:

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

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

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

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

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

Boiling or dew curve:

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

References: [22]

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

Function Name:	**v_ptx_H2**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION VPTXH2(P,T,X,NP)** REAL*8 P,T,X,NP
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_VPTXH2(V,P,T,X,NP)** 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Temperature range:

H_2 – Para (NP = 0):

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

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

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

H_2 – Normal (NP = 1):

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

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

from $t_{trip} = -259.193$°C to 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 <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

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

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

Results for wrong input values

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

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

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

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

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

Boiling or dew curve:

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

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

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

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

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

Boiling or dew curve:

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

References: [22]

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

Function Name:	**w_ptx_H2**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION WPTXH2(P,T,X,NP)** REAL*8 P,T,X,NP
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_WPTXH2(W,P,T,X,NP)** 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Temperature range:

H_2 – Para (NP = 0):

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

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

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

H_2 – Normal (NP = 1):

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

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

from $t_{trip} = -259.193$°C to 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* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* between 0 and 1. When calculating wet steam and *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Boiling and dew curve:

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

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

Results for wrong input values

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

H_2-Normal (NP = 1):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

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

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

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

Boiling or dew curve:

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

H_2-Para (NP = 0):

Single phase region:

(x = - 1)

p > 1210 bar or p < 0.001 bar or

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

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

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

Boiling or dew curve:

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

References: [22]

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

Function Name:	**x_ph_H2**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION XPHH2(P,H,NP)** REAL*8 P,H,NP
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_XPHH2(T,P,H,NP)** 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Temperature range:

H_2 – Para (NP = 0):

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

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

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

H_2 – Normal (NP = 1):

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

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

from $t_{trip} = -259.193$°C to 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:

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

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

Results for wrong input values

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

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

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

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

References: [22]

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

Function Name:	**x_ps_H2**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION XPSH2(P,S,NP)** REAL*8 P,S,NP
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_XPSH2(X,P,S,NP)** 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 H_2 – Normal or H_2 – Para

Result

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

Range of validity

Temperature range:

H_2 – Para (NP = 0):

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

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

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

H_2 – Normal (NP = 1):

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

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

from $t_{trip} = -259.193$°C to 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:

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

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

Results for wrong input values

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

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

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

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

References: [22]

KCE ThermoFluidProperties

KCE-ThermoFluidProperties
www.thermofluidprop.com

Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

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

Water and Steam

Library LibIF97

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

Library LibIF97_META

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

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:

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

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

Consideration of:

- Dissociation from VDI 4670
- Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:

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

Consideration of:

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

Extremely Fast Property Calculations

Spline-Based Table Look-up Method (SBTL)

Library LibSBTL_IF97
Library LibSBTL_95
Library LibSBTL_HuAir

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

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

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

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Humid Air

Library ASHRAE LibHuAirProp

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

Consideration of:

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

www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bücker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bücker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

Helmholtz energy equation for the mixing term

(also useable for calculating the Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

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

Formulation of the International Institute of Refrigeration (IIR 2010)

Ethanol

Library LibC2H5OH

Formulation of
Schroeder et al. (2014)

Methanol

Library LibCH3OH

Formulation of
de Reuck and Craven (1993)

Propane

Library LibPropane

Formulation of
Lemmon et al. (2009)

Siloxanes as ORC Working Fluids

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

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Nitrogen and Oxygen

Libraries LibN2 and LibO2

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

Hydrogen

Library LibH2

Formulation of
Leachman et al. (2009)

Helium

Library LibHe

Formulation of
Arp et al. (1998)

Hydrocarbons

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

Isopentane C_5H_{12} **Library LibC5H12_Iso**

Neopentane C_5H_{12} **Library LibC5H12_Neo**

Isohexane C_6H_{14} **Library LibC6H14**

Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

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

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

Hydrogen sulfide H_2S **Library LibH2S**

Nitrous oxide N_2O **Library LibN2O**

Sulfur dioxide SO_2 **Library LibSO2**

Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

KCE ThermoFluidProperties

For more information please contact:

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

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

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

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

www.thermofluidprop.com

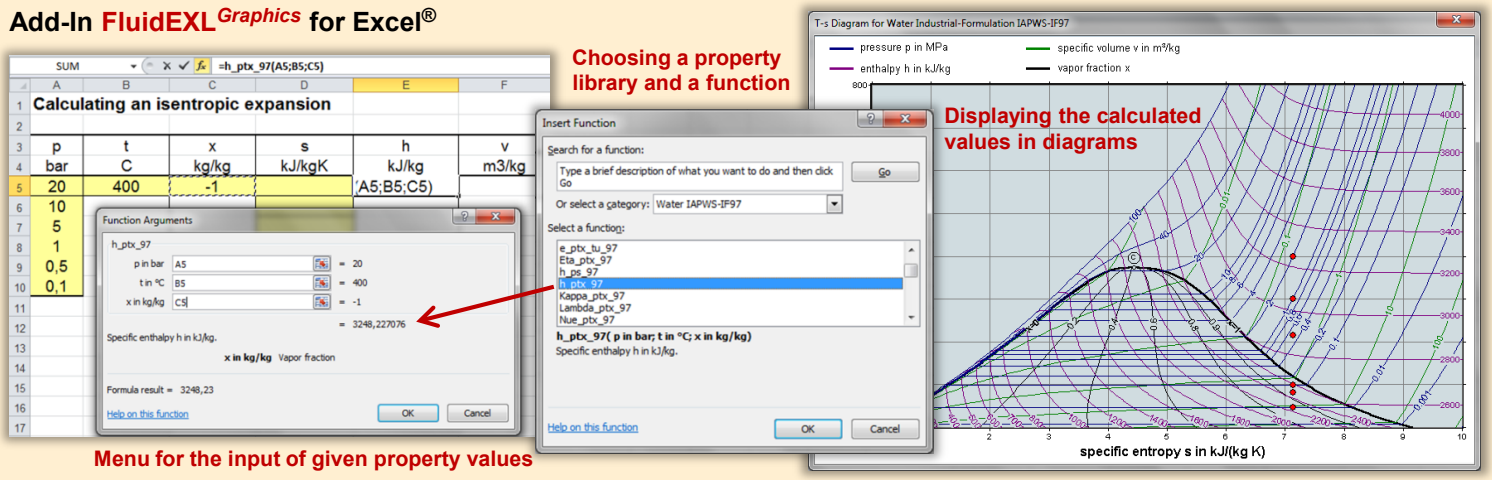
KCE-ThermoFluidProperties
www.thermofluidprop.com

KCE ThermoFluidProperties

Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

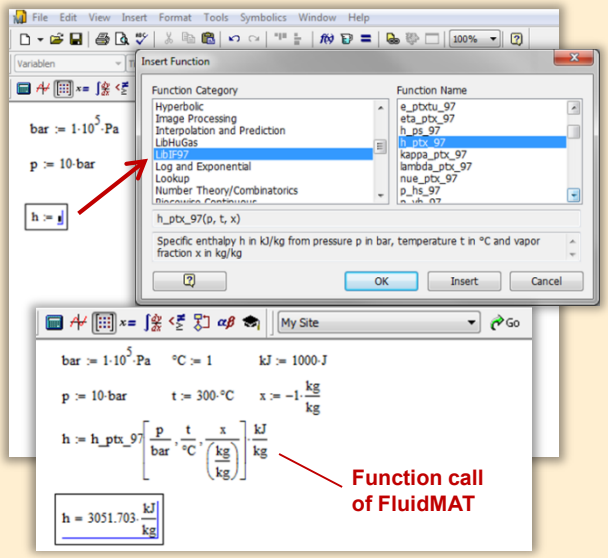
Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Add-In FluidEXL*Graphics* for Excel®



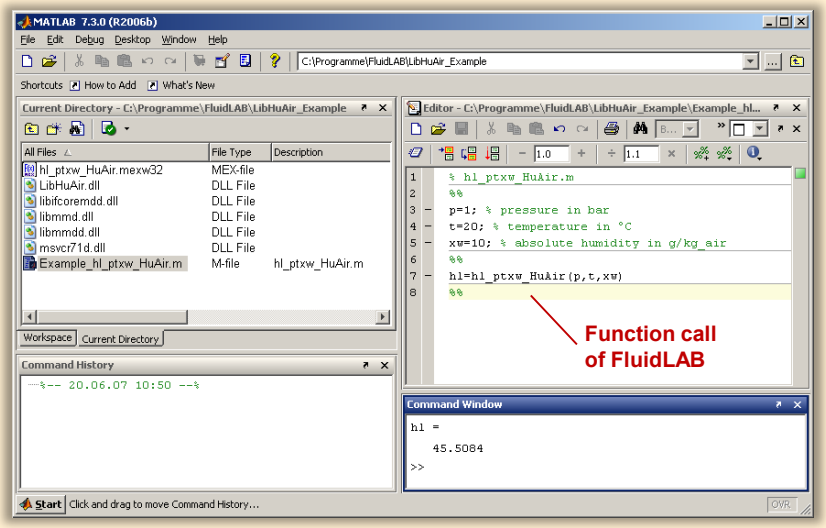
Add-On FluidMAT for Mathcad®
Add-On FluidPRIME for Mathcad Prime®

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



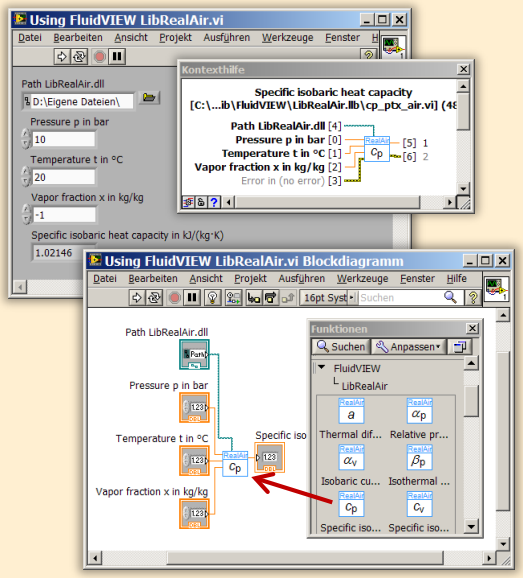
Add-On FluidLAB for MATLAB® and SIMULINK®

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



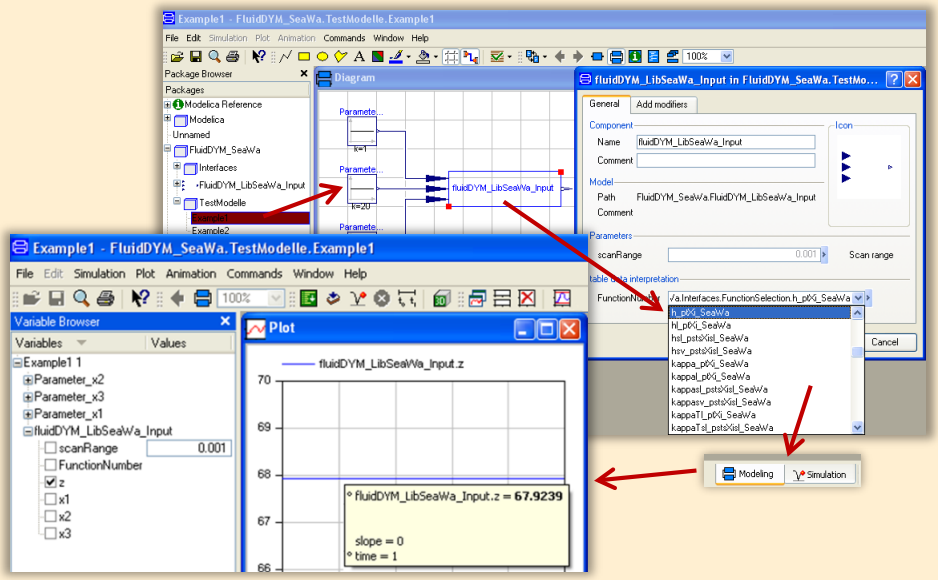
Add-On FluidVIEW for LabVIEW™

The property functions can be calculated in LabVIEW™.

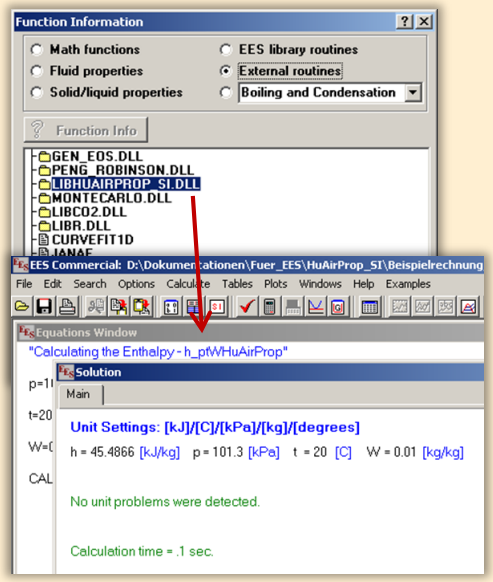


Add-On FluidDYM for DYMOLA® (Modelica) and SimulationX®

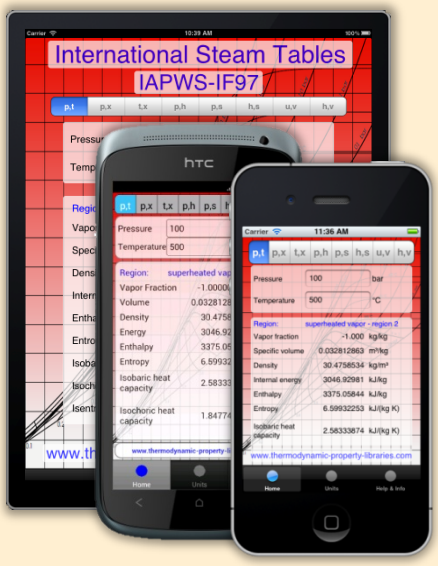
The property functions can be called in DYMOLA® and SimulationX®.



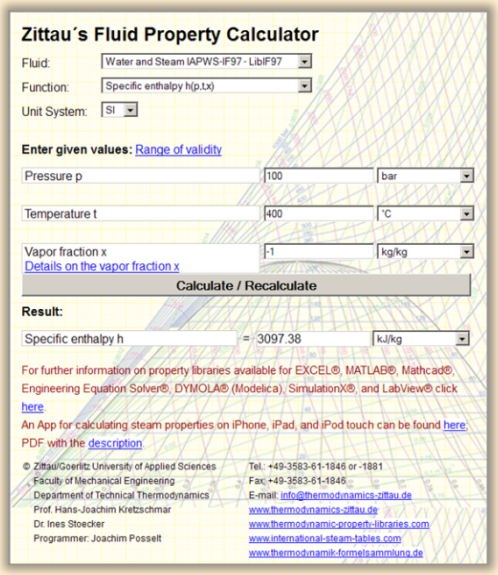
Add-On FluidEES for Engineering Equation Solver®



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



Online Property Calculator at www.thermofluidprop.com



Property Software for Pocket Calculators

FluidCasio

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

FluidHP

HP 48 | HP 49

FluidTI

TI Nspire CX CAS
TI Nspire CAS

TI 83
TI 84
TI 89

TI Voyage 200

TI 92

For more information please contact:

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Prof. Dr. Hans-Joachim Kretzschmar
Wallotstr. 3
01307 Dresden, Germany

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

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

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

www.thermofluidprop.com

5. References

[1] Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam IAPWS-IF97.
IAPWS Sekretariat, Dooley, B, EPRI, Palo Alto CA (1997)

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[5] Kretzschmar, H.-J.:
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[6] Revised Release on the IAPS Formulation 1985 for the Thermal Conductivity of Ordinary Water Substance.
IAPWS Sekretariat, Dooley, B., EPRI, Palo Alto CA, (1997)

[7] Revised Release on the IAPS Formulation 1985 for the Viscosity of Ordinary Water Substance.
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Supplementary Equations $v(p,T)$ for the Critical Region to the New Industrial Formulation IAPWS-IF97 for Water and Steam.
in: Steam, Water and Hydrothermal Systems: Physics and Chemistry Meeting the Needs of Industry, Proceedings of the 13th International Conference on the Properties of Water and Steam, Eds. P.G. Hill et al., NRC Press, Ottawa, (2000)

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ASME Journal of Engineering for Gas Turbines and Power - in Vorbereitung

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[14] VDI Richtlinie 4670
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6. Satisfied Customers

Date: 05/2018

The following companies and institutions use the property libraries

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

2018

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

2017

Compact Kältetechnik, Dresden	12/2017
Endress + Hauser Messtechnik GmbH +Co. KG, Hannover	12/2017
TH Mittelhessen, Gießen	11/2017
Haarslev Industries, Søndersø, 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, Bellevne (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 (2x)
IEV KEMA - DNV GV – Energie, Dresden	02/2016
Allborg University, Department of Energie, Aalborg, Denmark	02/2016
G.A.M. Heat GmbH, Gräfenhainichen	02/2016
Institut für Luft- und Kältetechnik, Dresden	02/2016, 05/2016, 06/2016
Bosch, Stuttgart	02/2016
INL Idaho National Laboratory, Idaho, USA	11/2016, 01/2016
Friedl ID, Wien, Austria	01/2016
Technical University of Dresden, Dresden	01/2016

2015

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

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

2014

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

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

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

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

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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
GKS, Schweinfurt	07/2012
COMPAREX, Leipzig for RWE Essen	07/2012
GEA, Nobitz	07/2012
Meyer Werft, Papenburg	07/2012
STEAG, Herne	07/2012
GRS, Cologne	06/2012
Fichtner IT Consult, Chennai, India	06/2012
Siemens, Freiburg	06/2012
Nikon Research of America, Belmont, USA	06/2012
Niederrhein University of Applied Sciences, Krefeld	06/2012
STEAG, Zwingenberg	06/2012
Mainova, Frankfurt on Main via Fichtner IT Consult	05/2012
Endress & Hauser	05/2012
PEU, Espenheim	05/2012
Luzern University of Applied Sciences, Switzerland	05/2012

BASF, Ludwigshafen (general license) via Fichtner IT Consult	05/2012
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Vattenfall, Berlin	04/2012
ALSTOM, Baden	04/2012
SKW, Piesteritz	04/2012
TERA Ingegneria, Trento, Italy	04/2012
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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 Destilation, 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
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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
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Fels, Elingerode	07/2011
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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
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INEOS, Cologne	04/2011
Enseleit Consulting Engineers, Siebigerode	04/2011
Witt Consulting Engineers, Stade	03/2011
Helbling, Zurich, Switzerland	03/2011
MAN Diesel, Copenhagen, Denmark	03/2011
AGO, Kulmbach	03/2011
University of Duisburg	03/2011, 06/2011
CCP, Marburg	03/2011
BASF, Ludwigshafen	02/2011
ALSTOM Power, Baden, Switzerland	02/2011
Universität der Bundeswehr, Munich	02/2011
Calorifer, Elgg, Switzerland	01/2011
STRABAG, Vienna, Austria	01/2011
TUEV Sued, Munich	01/2011
ILK Dresden	01/2011
Technical University of Dresden	01/2011, 05/2011 06/2011, 08/2011

2010

Umweltinstitut Neumarkt	12/2010
YIT Austria, Vienna, Austria	12/2010
MCI Innsbruck, Austria	12/2010

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

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

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

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

2008

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

Technip Benelux BV, Zoetermeer, Netherlands	08/2008
Fennovoima Oy, Helsinki, Finland	08/2008
Fichtner Consulting & IT, Stuttgart	09/2008
PEU, Espenhain	09/2008
Poyry, Dresden	09/2008
WINGAS, Kassel	09/2008
TUEV Sued, Dresden	10/2008
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	10/2008, 11/2008
AWTEC, Zurich, Switzerland	11/2008
Siemens Power Generation, Erlangen	12/2008

2007

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

Wiesbaden University of Applied Sciences, Department of Engineering Sciences	10/2007
Endress+Hauser Messtechnik, Hannover	11/2007
Munich University of Applied Sciences, Department of Mechanical Engineering	11/2007
Rerum Cognitio, Zwickau	12/2007
Siemens Power Generation, Erlangen	11/2007
University of Rostock, Chair in Technical Thermodynamics	11/2007, 12/2007

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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, Department of Thermal Fluid Flow Engines	02/2006
Technical University of Munich, Chair in Apparatus and Plant Engineering	02/2006
Energietechnik Leipzig (company license),	02/2006
Siemens Power Generation, Erlangen	02/2006, 03/2006
RWE Power, Essen	03/2006
WAETAS, Pobershau	04/2006
Siemens Power Generation, Goerlitz	04/2006
Technical University of Braunschweig, Department of Thermodynamics	04/2006
EnviCon & Plant Engineering, Nuremberg	04/2006
Brassel Engineering, Dresden	05/2006
University of Halle-Merseburg, Department of USET Merseburg incorporated society	05/2006
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	05/2006
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	05/2006
Suedzucker, Ochsenfurt	06/2006
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Feistel Engineering, Volkach	07/2006
ThyssenKrupp Marine Systems, Kiel	07/2006

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Konstanz University of Applied Sciences, Course of Studies Construction and Development	10/2006
Siemens Power Generation, Duisburg	10/2006
Hannover University of Applied Sciences, Department of Mechanical Engineering	10/2006
Siemens Power Generation, Berlin	11/2006
Zikesch Armaturentechnik, Essen	11/2006
Wismar University of Applied Sciences, Seafaring Department	11/2006
BASF, Schwarzheide	12/2006
Enertech Energie und Technik, Radebeul	12/2006

2005

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

Midiplan, Bietigheim-Bissingen	11/2005
Technical University of Freiberg, Chair in Hydrogeology	11/2005
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University of Stuttgart, Institute of Thermodynamics and Heat Engineering	02/2004
MAN B&W Diesel A/S, Copenhagen, Denmark	02/2004
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Ulm University of Applied Sciences	03/2004
Visteon, Kerpen	03/2004, 10/2004
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	04/2004
Rerum Cognitio, Zwickau	04/2004
University of Saarbruecken	04/2004
Grenzebach BSH, Bad Hersfeld	04/2004
SOFBID Zwingenberg (general EBSILON program license)	04/2004
EnBW Energy Solutions, Stuttgart	05/2004
HEW-Kraftwerk, Tiefstack	06/2004
h s energieanlagen, Freising	07/2004
FCIT, Stuttgart	08/2004
Physikalisch Technische Bundesanstalt (PTB), Braunschweig	08/2004
Mainova Frankfurt	08/2004
Rietschle Energieplaner, Winterthur, Switzerland	08/2004
MAN Turbo Machines, Oberhausen	09/2004
TUEV Sued, Dresden	10/2004
STEAG Kraftwerk, Herne	10/2004, 12/2004
University of Weimar	10/2004
energeticals (e-concept), Munich	11/2004
SorTech, Halle	11/2004
Enertech EUT, Radebeul (company license)	11/2004
Munich University of Applied Sciences	12/2004
STORA ENSO Sachsen, Eilenburg	12/2004
Technical University of Cottbus, Chair in Power Plant Engineering	12/2004
Freudenberg Service, Weinheim	12/2004

2003

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

Wulff Energy Systems, Husum	01/2003
Technip Benelux BV, Zoetermeer, Netherlands	01/2003
ALSTOM Power, Baden, Switzerland	01/2003, 07/2003
VER, Dresden	02/2003
Rietschle Energieplaner, Winterthur, Switzerland	02/2003
DLR, Leupholdhausen	04/2003
Emden University of Applied Sciences, Department of Technology	05/2003
Petterssson+Ahrends, Ober-Moerlen	05/2003
SOFBID ,Zwingenberg (general EBSILON program license)	05/2003
Ingenieurbuero Ostendorf, Gummersbach	05/2003
TUEV Nord, Hamburg	06/2003
Muenstermann GmbH, Telgte-Westbevern	06/2003
University of Cali, Colombia	07/2003
Atlas-Stord, Rodovre, Denmark	08/2003
ENERKO, Aldenhoven	08/2003
STEAG RKB, Leuna	08/2003
eta Energieberatung, Pfaffenhofen	08/2003
exergie, Dresden	09/2003
AWTEC, Zurich, Switzerland	09/2003
Energie, Timelkam, Austria	09/2003
Electrowatt-EKONO, Zurich, Switzerland	09/2003
LG, Annaberg-Buchholz	10/2003
FZR Forschungszentrum, Rossendorf/Dresden	10/2003
EnviCon & Plant Engineering, Nuremberg	11/2003
Visteon, Kerpen	11/2003
VEO Vulkan Energiewirtschaft Oderbruecke, Eisenhuettenstadt	11/2003
Stadtwerke Hannover	11/2003
SaarEnergie, Saarbruecken	11/2003
Fraunhofer-Gesellschaft, Munich	12/2003
Erfurt University of Applied Sciences, Department of Supply Engineering	12/2003
SorTech, Freiburg	12/2003
Mainova, Frankfurt	12/2003
Energieversorgung Halle	12/2003

2002

Hamilton Medical AG, Rhaezuens, Switzerland	01/2002
Bochum University of Applied Sciences, Department of Thermo- and Fluid Dynamics	01/2002
SAAS, Possendorf/Dresden	02/2002
Siemens, Karlsruhe (general license for the WinIS information system)	02/2002

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Stadtwerke Hannover	09/2002
Siemens Power Generation, Goerlitz	10/2002
Energieversorgung Halle (company license)	10/2002
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G.U.N.T. Geraetebau, Barsbuettel	12/2002
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2001

ALSTOM Power, Baden, Switzerland	01/2001, 06/2001
	12/2001
KW2 B. V., Amersfoot, Netherlands	01/2001, 11/2001
Eco Design, Saitamaken, Japan	01/2001
M&M Turbine Technology, Bielefeld	01/2001, 09/2001
MVV Energie, Mannheim	02/2001
Technical University of Dresden, Department of	02/2001
Power Machinery and Plants	
PREUSSAG NOELL, Wuerzburg	03/2001
Fichtner Consulting & IT Stuttgart	04/2001
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Muenstermann GmbH, Telgte-Westbevern	05/2001
SaarEnergie, Saarbruecken	05/2001
Siemens, Karlsruhe	08/2001
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Neusiedler AG, Ulmerfeld, Austria	09/2001

h s energieanlagen, Freising	09/2001
Electrowatt-EKONO, Zurich, Switzerland	09/2001
IPM Zittau/Goerlitz University of Applied Sciences (general license)	10/2001
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ALSTOM Power Baden, Switzerland	12/2001
VEAG, Berlin (group license)	12/2001

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SOFBID, Zwingenberg	01/2000
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AG KKK - PGW Turbo, Leipzig	01/2000
PREUSSAG NOELL, Wuerzburg	01/2000
M&M Turbine Technology, Bielefeld	01/2000
IBR Engineering Reis, Nittendorf-Undorf	02/2000
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