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Property Library for Hydrogen

FluidEXL *Graphics*
with **LibH2**
for Excel®

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Property Program Library for Hydrogen FluidEXL^{Graphics} LibH2

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0. Package Contents

0.1 Zip files for 32-bit Office®

The following zip files are delivered for your computer running a 32-bit Office® version.

English zip file "CD_FluidEXL_Graphics_LibH2_Eng.zip" including the following files:

FluidEXL_Graphics_Eng_Setup.exe	- English installation program for the Add-In FluidEXL <i>Graphics</i> for use in Excel®.
FluidEXL_Graphics_Eng.xla	- English Add-In for FluidEXL <i>Graphics</i>
LibH2.dll	- Dynamic Link Library for use in Windows programs
LibH2.hlp	- Help file for the LibH2 property library
FluidEXL_Graphics_LibH2_Docu_Eng.pdf	- User's Guide

German zip file "CD_FluidEXL_Graphics_LibH2.zip" including the following files:

FluidEXL_Graphics_Setup.exe	- German installation program for the Add-In FluidEXL <i>Graphics</i> for application in Excel®.
FluidEXL_Graphics.xla	- German Add-In for FluidEXL <i>Graphics</i>
LibH2.dll	- Dynamic Link Library for use in Windows programs
LibH2.hlp	- Help file for the LibH2 property library
FluidEXL_Graphics_LibH2_Docu_Eng.pdf	- User's Guide

0.2 Zip files for 64-bit Office®

The following zip files are delivered for your computer running a 64-bit Office® version.

English zip file "CD_FluidEXL_Graphics_LibH2_x64_Eng.zip" including the following files and folders:

Files:

FluidEXL_Graphics_LibH2_Docu_Eng.pdf	- User's Guide
FluidEXL_Graphics_Eng.xla	- English FluidEXL <i>Graphics</i> Add-In
FluidEXL_Graphics_Eng_64_Setup.msi	- Self-extracting and self-installing program
LibH2.dll	- Dynamic link library for use in Windows® programs

LibH2.hlp	- Help file for the LibH2 property library
Setup.exe	- Self-extracting and self-installing program for FluidEXL ^{Graphics}

Folders:

vcredist_x64	- Folder containing the "Microsoft Visual C++ 2010 x64 Redistributable Pack"
WindowsInstaller3_1	- Folder containing the "Microsoft Windows Installer"

German zip file "CD_FluidEXL_Graphics_LibH2_x64.zip" including the following files and folders:

Files:

FluidEXL_Graphics_LibH2_Docu_Eng.pdf	- User's Guide
FluidEXL_Graphics.xla	- German FluidEXL ^{Graphics} Add-In
FluidEXL_Graphics_64_Setup.msi	- Self-extracting and self-installing program
LibH2.dll	- Dynamic link library for use in Windows [®] programs
LibH2.hlp	- Help file for the LibH2 property library
Setup.exe	- Self-extracting and self-installing program for FluidEXL ^{Graphics}

Folders:

vcredist_x64	- Folder containing the "Microsoft Visual C++ 2010 x64 Redistributable Pack"
WindowsInstaller3_1	- Folder containing the "Microsoft Windows Installer"

1. Property Functions

Functional Dependence	Function Name	Call from Fortran program	Call in DLL LibH2 as parameter	Property or Function	Unit of the result
$a = f(p, t, x, NP)$	a_ptx_H2	APTXXH2(P,T,X,NP)	C_APTXXH2(A,P,T,X,NP)	Thermal diffusivity	m ² /s
$c_p = f(p, t, x, NP)$	cp_ptx_H2	CPPTXXH2(P,T,X,NP)	C_CPPTXXH2(CP,P,T,X,NP)	Specific isobaric heat capacity	kJ/(kg K)
$c_v = f(p, t, x, NP)$	cp_ptx_H2	CVPTXXH2(P,T,X,NP)	C_CVPTXXH2(CV,P,T,X,NP)	Specific isochoric heat capacity	kJ/(kg K)
$\eta = f(p, t, x, NP)$	eta_ptx_H2	ETAPTXH2(P,T,X,NP)	C_ETAPTXH2(ETA,P,T,X,NP)	Dynamic viscosity	Pa s
$h = f(p, t, x, NP)$	h_ptx_H2	HPTXXH2(P,T,X,NP)	C_HPTXXH2(H,P,T,X,NP)	Specific enthalpy	kJ/kg
$\kappa = f(p, t, x, NP)$	kappa_ptx_H2	KAPPTXXH2(P,T,X,NP)	C_KAPPTXXH2(KAP,P,T,X,NP)	Isentropic exponent	-
$\lambda = f(p, t, x, NP)$	lambda_ptx_H2	LAMPTXXH2(P,T,X,NP)	C_LAMPTXXH2(LAM,P,T,X,NP)	Thermal conductivity	W/(m K)
$\nu = f(p, t, x, NP)$	ny_ptx_H2	NYPTXXH2(P,T,X,NP)	C_NYPTXXH2(NY,P,T,X,NP)	Kinematic viscosity	m ² /s
$p_{\text{mel}} = f(t, NP)$	pmel_t_H2	PMELTH2(T,NP)	C_PMELTH2(PMEL,T,NP)	Melting pressure from temperature	bar
$p_s = f(t, NP)$	ps_t_H2	PSTH2(T,NP)	C_PSTH2(PS,T,NP)	Vapor pressure from temperature	bar
$Pr = f(p, t, x, NP)$	Pr_ptx_H2	PRPTXXH2(P,T,X,NP)	C_PRPTXXH2(PR,P,T,X,NP)	<i>Prandtl</i> -Number	-
$\rho = f(p, t, x, NP)$	rho_ptx_H2	RHOPTXXH2(P,T,X,NP)	C_RHOPTXXH2(RHO,P,T,X,NP)	Density	kg/m ³
$s = f(p, t, x, NP)$	s_ptx_H2	SPTXXH2(P,T,X,NP)	C_SPTXXH2(S,P,T,X,NP)	Specific entropy	kJ/(kg K)
$t = f(p, h, NP)$	t_ph_H2	TPHH2(P,H,NP)	C_TPHH2(T,P,H,NP)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p, s, NP)$	t_ps_H2	TPSH2(P,S,NP)	C_TPSH2(T,P,S,NP)	Backward function: Temperature from pressure and entropy	°C
$t_{\text{mel}} = f(p, NP)$	tmel_p_H2	TMELPH2(P,NP)	C_TMELPH2(TMEL,P,NP)	Melting temperature from pressure	°C
$t_s = f(p, NP)$	ts_p_H2	TSPH2(P,NP)	C_TSPH2(TS,P,NP)	Boiling temperature from pressure	°C
$u = f(p, t, x, NP)$	u_ptx_H2	UPTXXH2(P,T,X,NP)	C_UPTXXH2(U,P,T,X,NP)	Internal energy	kJ/kg
$v = f(p, t, x, NP)$	v_ptx_H2	VPTXXH2(P,T,X,NP)	C_VPTXXH2(V,P,T,X,NP)	Specific volume	m ³ /kg
$w = f(p, t, x, NP)$	w_ptx_H2	WPTXXH2(P,T,X,NP)	C_WPTXXH2(W,P,T,X,NP)	Isentropic speed of sound	m/s ²
$x = f(p, h, NP)$	x_ph_H2	XPHH2(P,H,NP)	C_XPHH2(X,P,H,NP)	Backward function: Vapor fraction from pressure and enthalpy	kg/kg
$x = f(p, s, NP)$	x_ps_H2	XPSH2(P,S,NP)	C_XPSH2(X,P,S,NP)	Backward function: Vapor fraction from pressure and entropy	kg/kg

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

Hints for the parameter NP

Hydrogen can be calculated as H₂-Normal and H₂-Para. The form is specified by the parameter NP.

The parameter NP can take the following values: NP = 1, for H₂-Normal,
 NP = 0, for H₂-Para.

Details on the vapor fraction x

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

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

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

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

Wet steam region:

H ₂ -Para (NP = 0):	Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar
H ₂ -Normal (NP = 1):	Temperature range from $t_t = -259.193$ °C to $t_c = -240.212$ °C Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

Range of validity

Temperature range:

H₂-Para (NP = 0):

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

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

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

H₂-Normal (NP = 1):

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

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

from $t_{\text{trip}} = -259.193$ °C to 126.85 °C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Specifications for calculating the state variables of hydrogen

The calculation of the state variables of H₂-Normal und H₂-Para is based upon the following approximations:

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

The calculation of the state variables H₂-Normal and H₂-Para varies only in the different equations of the isobaric heat capacity of the ideal gas.

Reference state

$h = 0$ and $s = 0$

at $p = 1.01325$ bar

and $t = -252.8731$ °C

Hint!

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

2. Application of FluidEXL^{Graphics} in Excel[®]

The FluidEXL^{Graphics} Add-In has been developed to calculate thermodynamic properties in Excel more conveniently. Within Excel[®], it enables the direct call of functions relating to hydrogen from the LibH2 property library.

2.1 Installing FluidEXL^{Graphics}

If FluidEXL^{Graphics} has not yet been installed or if there is a version installed which has been delivered before June 2010, please complete the initial installation procedure described below.

If FluidEXL^{Graphics} has already been installed in a version which has been delivered after June 2010, you simply need to copy the files which belong to the LibH2 library. In this case, follow the subsection "Adding the LibH2 Library" on page 2/11.

Installing FluidEXL^{Graphics} for 32-bit Office[®]

In this section, the installation of FluidEXL^{Graphics} for a 32-bit Office[®] version is described. Before you begin, it is best to uninstall any trial version or full version of FluidEXL^{Graphics} delivered before June 2010.

After you have downloaded and extracted the zip-file

"CD_FluidEXL_Graphics_LibH2_Eng.zip" (for English version of Windows)

"CD_FluidEXL_Graphics_LibH2.zip" (for German version of Windows)

you will see the folder

CD_FluidEXL_Graphics_LibH2_Eng (for English version of Windows)

CD_FluidEXL_Graphics_LibH2 (for German version of Windows)

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:

FluidEXL_Graphics_Eng_Setup.exe (for English version of Windows)

FluidEXL_Graphics_Setup.exe (for German version of Windows)

FluidEXL_Graphics_Eng.xla (for English version of Windows)

FluidEXL_Graphics.xla (for German version of Windows)

FluidEXL_Graphics_LibH2_Docu_Eng.pdf

LibH2.dll

LibH2.hlp.

In order to run the installation of FluidEXL^{Graphics} double-click the file

FluidEXL_Graphics_Eng_Setup.exe (for English version of Windows)

FluidEXL_Graphics_Setup.exe (for German version of Windows).

Installation may start with a window noting that all Windows programs should be closed. When this is the case, the installation can be continued. Click the "Next >" button.

In the following dialog box, "Choose Destination Location", the default path offered automatically for the installation of FluidEXL^{Graphics} is

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
 C:\Programme\FluidEXL_Graphics (for German version of Windows).

By clicking the "Browse..." button, you can change the installation directory before installation (see figure below).



Figure 2.1: Choose Destination Location

Finally, click on "Next" to continue installation; click "Next" again in the "Start Installation" window which follows in order to start the installation of FluidEXL *Graphics*.

After FluidEXL *Graphics* has been installed, the sentence "FluidEXL Graphics English has been successfully installed." will be shown. Confirm this by clicking the "Finish" button.

Close the "Control Panel" window. The installation of FluidEXL *Graphics* has been completed.

During the installation process the following files

Advapi32.dll	LC.dll
Dformd.dll	Msvcp60.dll
Dforrt.dll	Msvcrt.dll
UNWISE.EXE	UNWISE.INI
INSTALL_EXL.LOG	

have been copied into the chosen destination folder, in the standard case

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
 C:\Programme\FluidEXL_Graphics (for German version of Windows).

In the next step, the following files

FluidEXL_Graphics_Eng.xla	(for English version of Windows)
FluidEXL_Graphics.xla	(for German version of Windows)
LibH2.dll	
LibH2.hlp	

from the extracted folder

CD_FluidEXL_Graphics_LibH2_Eng	(for English version of Windows)
CD_FluidEXL_Graphics_LibH2	(for German version of Windows)

must be copied into the chosen destination folder (the standard being

C:\Program Files\FluidEXL_Graphics_Eng	(for English version of Windows)
C:\Programme\FluidEXL_Graphics	(for German version of Windows),

using an appropriate program such as Explorer or Norton Commander.

Installing FluidEXL *Graphics* for 64-bit Office®

In this section, the installation of FluidEXL *Graphics* for a 64-bit Office® version is described.

Before you begin, it is best to close any Windows® applications, since Windows® may need to be rebooted during the installation process.

After you have downloaded and extracted the zip-file

"CD_FluidEXL_Graphics_LibH2_x64_Eng.zip"	(for English version of Windows)
"CD_FluidEXL_Graphics_LibH2_x64.zip,"	(for German version of Windows)

you will see the folder

"CD_FluidEXL_Graphics_LibH2_Eng"	(for English version of Windows)
"CD_FluidEXL_Graphics_LibH2"	(for German version of Windows)

in your Windows Explorer®, Norton Commander®, or any other similar program you may be using.

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

Within this folder you will see the following files

FluidEXL_Graphics_LibH2_Docu_Eng	
FluidEXL_Graphics_Eng.xla	(for English version of Windows)
FluidEXL_Graphics.xla	(for German version of Windows)
FluidEXL_Graphics_Eng_Setup_64.msi	(for English version of Windows)
FluidEXL_Graphics_Setup_64.msi	(for German version of Windows)
LibH2.dll	
LibH2.hlp	
Setup.exe	

and the folders

vcredist_x64
WindowsInstaller3_1.

In order to run the installation of FluidEXL *Graphics*, double-click on the file

Setup.exe.

If the "Microsoft Visual C++ 2010 x64 Redistributable Pack" is not running on your computer yet, installation will start with a window noting that the "Visual C++ 2010 runtime library (x64)" will be installed on your machine (see Figure 2.2).

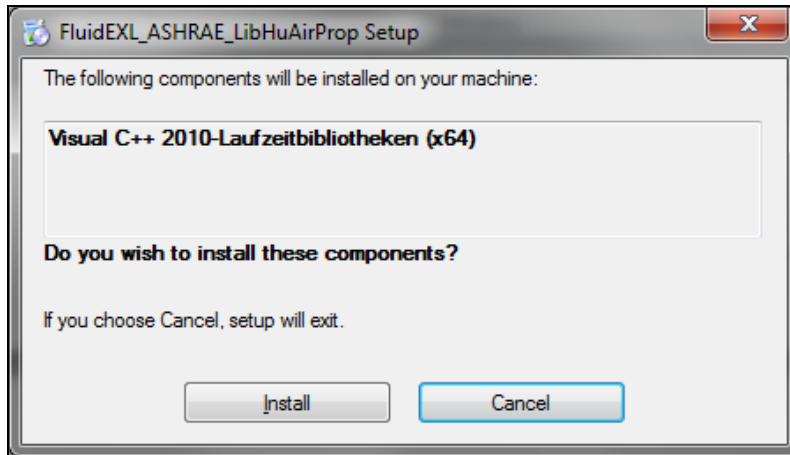


Figure 2.2: Installing the "Visual C++ 2010 runtime library (x64)"

Click on "Install" to continue.

In the following window you are required to accept the Microsoft® license terms to install the "Microsoft Visual C++ 2010 x64 Redistributable Pack" by ticking the box next to "I have read and accept the license terms" (see Figure 2.3).

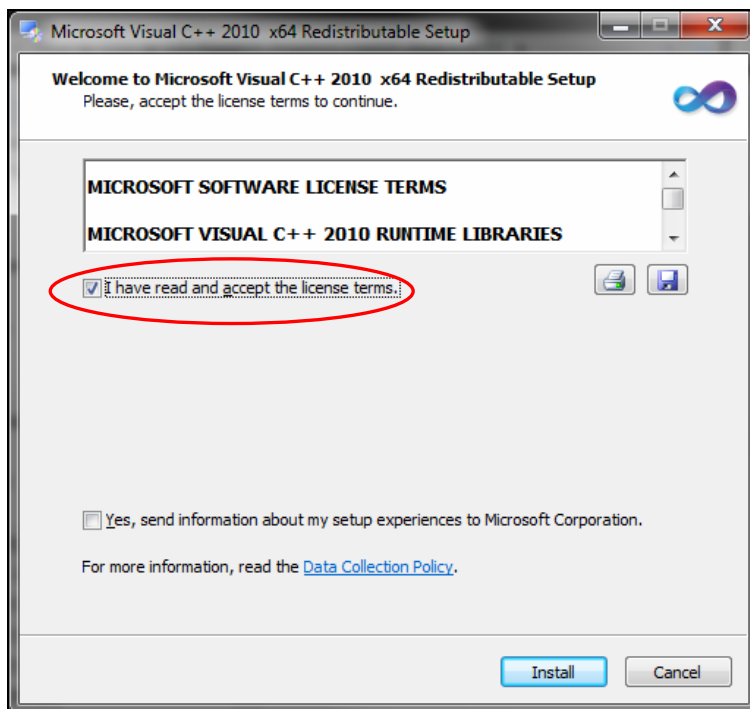


Figure 2.3: Accepting the license terms

Now click on "Install" to continue installation.

After the "Microsoft Visual C++ 2010 x64 Redistributable Pack" has been installed, you will see the sentence "Microsoft Visual C++ 2010 x64 Redistributable has been installed." Confirm this by clicking "Finish."

Now the installation of FluidEXL *Graphics* starts with a window noting that the installer will guide you through the installation. Click the "Next >" button to continue.

In the following dialog box, "Select Installation Folder," the default path offered automatically for the installation of FluidEXL *Graphics* is

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows).
 C:\Programme\FluidEXL_Graphics (for German version of Windows).

By clicking the "Browse..." button, you can change the installation directory before installation (see Figure 2.4).

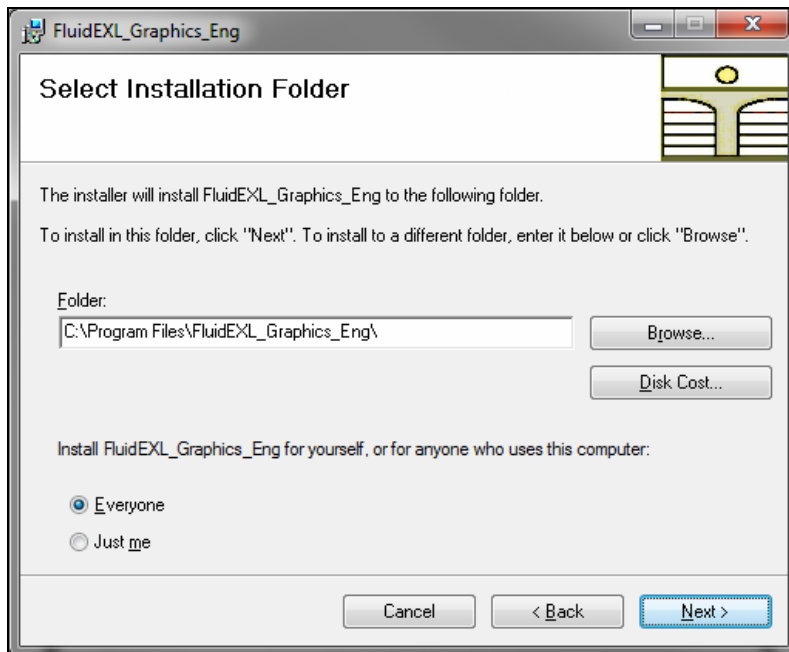


Figure 2.4: Choosing the installation folder

Finally, click on "Next >" to continue installation; click "Next >" again in the "Confirm Installation" window which follows in order to start the installation of FluidEXL *Graphics*.

After FluidEXL *Graphics* has been installed, you will see the sentence "FluidEXL_Graphics_Eng has been successfully installed." Confirm this by clicking the "Close" button.

The installation of FluidEXL *Graphics* has been completed.

During the installation process the following files

capt_ico_big.ico	libmmd.dll
libifcoremd.dll	LC.dll
libiomp5md.dll	

will have been copied into the destination folder chosen, the standard being

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
 C:\Programme\FluidEXL_Graphics (for German version of Windows).

In addition, the two subdirectories \FORMULATION97 and \FLuft were created in the destination folder.

In the next step, the files below

FluidEXL_Graphics_Eng.xla	(for English version of Windows)
FluidEXL_Graphics.xla	(for German version of Windows)

LibH2.dll
LibH2.hlp,

found in your CD folder, must be copied into the chosen destination folder (the standard being

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows))

using an appropriate program such as Explorer or Norton Commander.

2.2 Registering FluidEXL^{Graphics} as Add-In in Excel[®]

Registering FluidEXL^{Graphics} as Add-In in Excel[®], versions 2003 or earlier

After the installation of FluidEXL^{Graphics}, the program must be registered as an Add-In in Excel[®]. In order to do so, start Excel[®] and carry out the following steps:

- Click "Tools" in the upper menu bar of Excel.
- Here, click on "Add-Ins..." in the menu.

After a short delay the "Add-Ins" dialog box will appear.

- Click "Browse...".
- In the following dialog box, choose your chosen destination folder (the standard being
C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows))

here select

"FluidEXL_Graphics_Eng.xla" (for English version of Windows)
"FluidEXL_Graphics.xla" (for German version of Windows)

and afterwards click "OK".

- Now, the entry
"FluidEXL Graphics Eng" (for English version of Windows)
"FluidEXL Graphics" (for German version of Windows)
will appear in the Add-Ins list.

Note:

As long as the check box next to the file name

"FluidEXL Graphics Eng" (for English version of Windows)
"FluidEXL Graphics" (for German version of Windows)

is checked, this Add-In will be loaded automatically every time you start Excel until you unmark the box by clicking on it again.

- In order to register FluidEXL^{Graphics} as an Add-In, click "OK" in the "Add-Ins" dialog box.

Now, the new FluidEXL^{Graphics} menu bar will appear in the upper menu area of your Excel screen, marked with a red circle in the next figure.

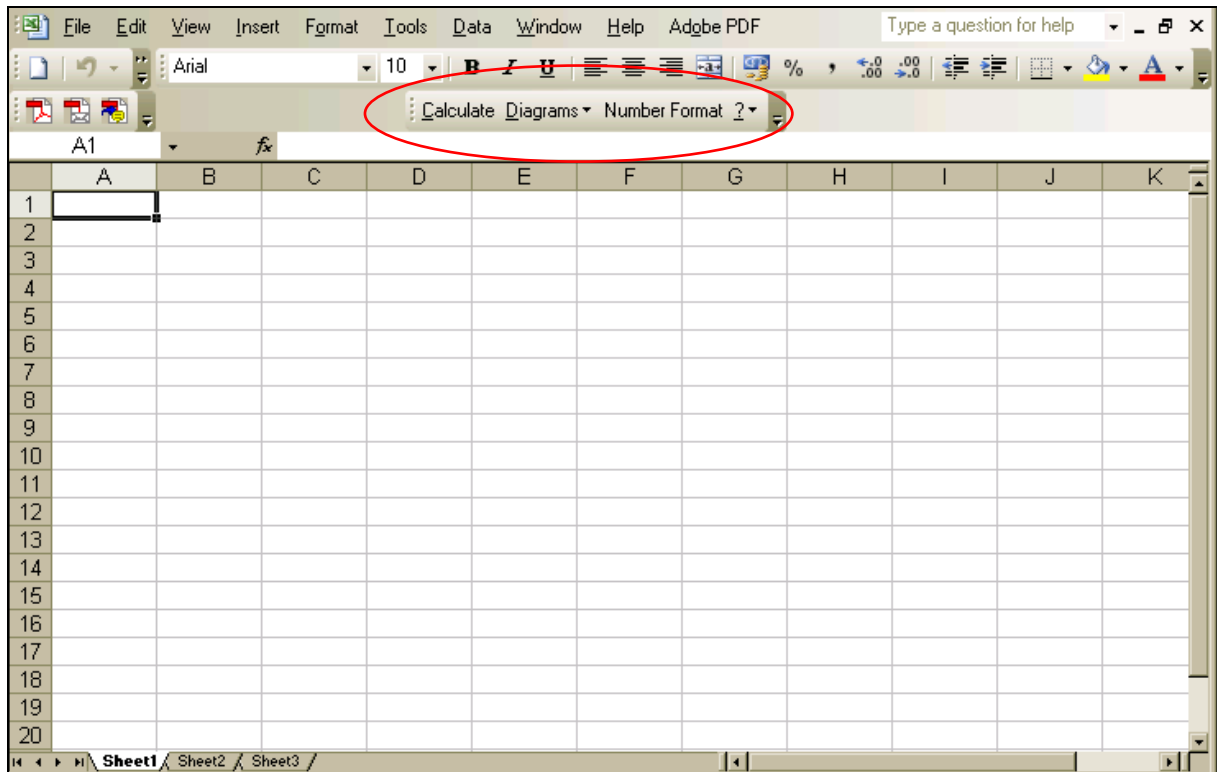


Figure 2.5: Menu bar of FluidEXL*Graphics*

From within Excel you can now select the "Hydrogen LibH2" DLL library property functions via this menu bar (see section 2.5 on page 2/19).

Registering FluidEXL *Graphics* as Add-In in Excel® 2007 (or later versions)

After installation in Windows®, FluidEXL *Graphics* must be registered in Excel® 2007 as an Add-In. For this, start Excel and carry out the following steps:

- Click the Windows Office button in the upper left hand corner of Excel
- Click on the "Excel Options" button in the menu which appears (see figure below)

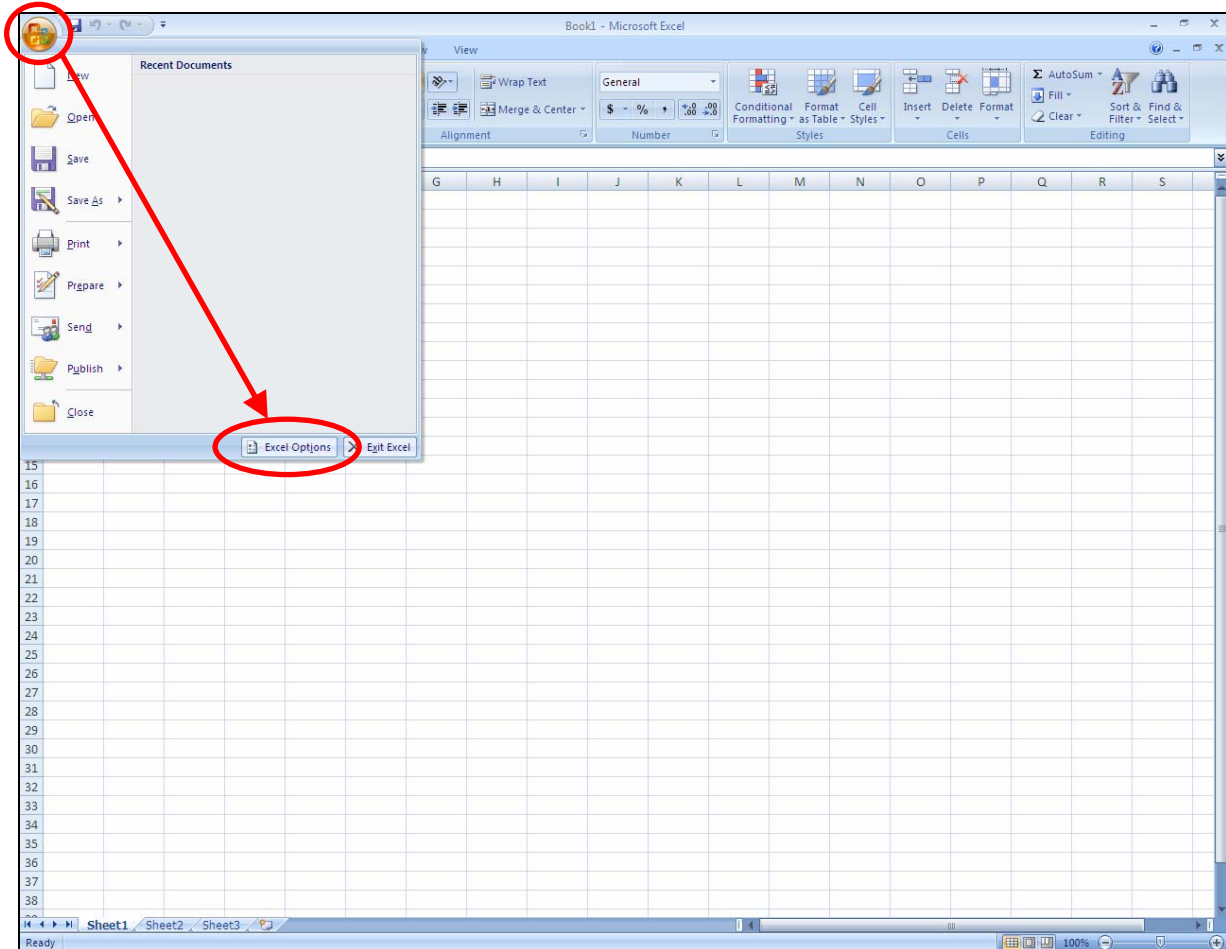


Figure 2.6: Registering FluidEXL *Graphics* as Add-In in Excel® 2007

- Click on "Add-Ins" in the next menu

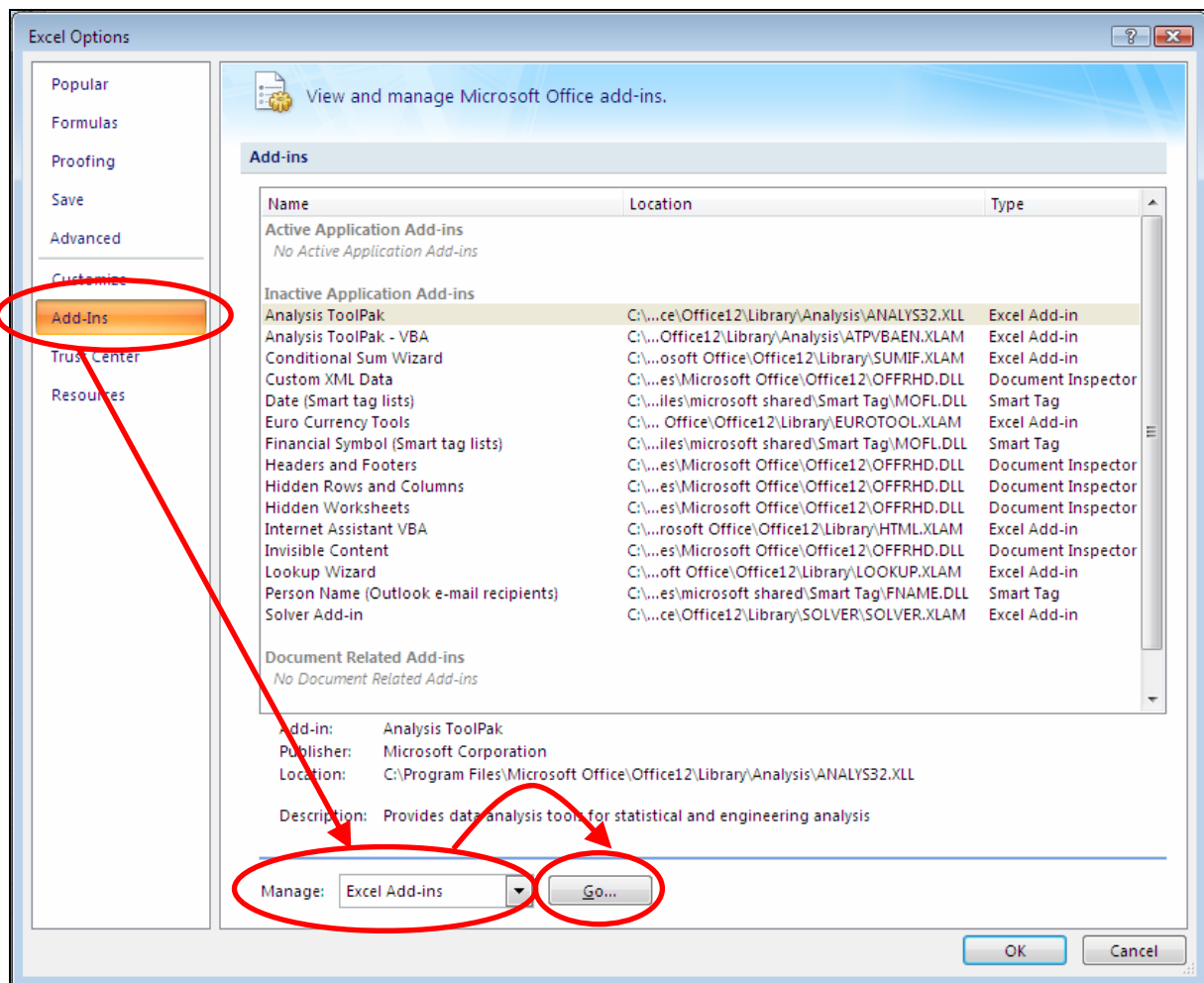


Figure 2.7: Dialog window "Add-Ins"

- Should it not be shown in the list automatically, select "Excel Add-ins" (found next to "Manage:" in the lower area of the menu)
- Then click the "Go..." button
- Click "Browse" in the following window and locate the destination folder, generally
 C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
 C:\Programme\FluidEXL_Graphics (for German version of Windows);
 within that folder click on the file named
 "FluidEXL_Graphics_Eng.xla" (for English version of Windows)
 "FluidEXL_Graphics.xla" (for German version of Windows)
 and then hit "OK."

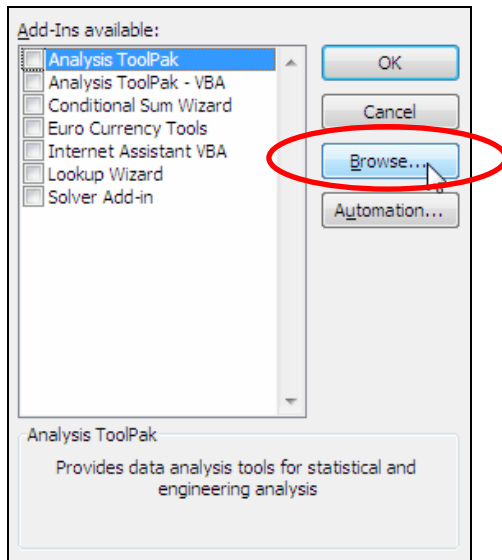


Figure 2.8: Dialog window "Add-Ins available"

- Now, "FluidEXL Graphics Eng" will be shown in your list of Add-Ins.
(If a check-mark is situated in the box next to the name "FluidEXL Graphics", this Add-In will automatically be loaded whenever Excel starts. This will continue to occur unless the check-mark is removed from the box by clicking on it.)

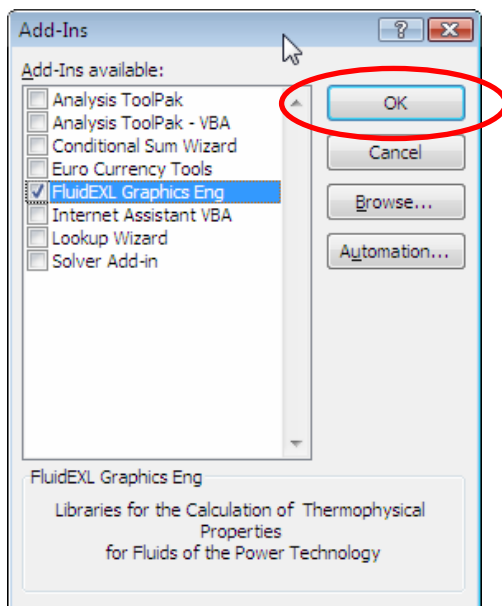


Figure 2.9: Dialog window "Add-Ins"

- In order to register the Add-In, click the "OK" button in the "Add-Ins" window.

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

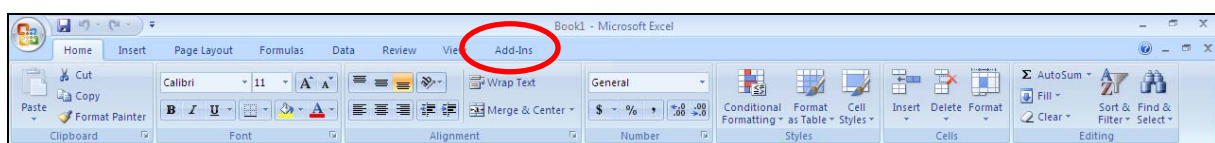


Figure 2.10: Menu item "Add-Ins"

In the upper menu region of Excel®, the FluidEXL^{Graphics} menu bar will appear as marked with the red circle in the next figure.

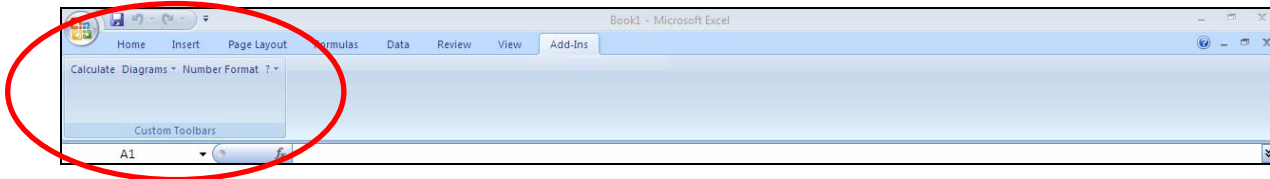


Figure 2.11: FluidEXL^{Graphics} menu bar

Installation of FluidEXL^{Graphics} in Excel (versions 2007 and later) is now finished. FluidEXL^{Graphics} can be used analogous to the description for using with earlier Excel versions.

Adding the LibH2 Library (FluidEXL^{Graphics} is already installed)

If FluidEXL^{Graphics} has already been installed in the April 2010 version, you only have to copy the following files provided in the extracted folder

CD_FluidEXL_Graphics_LibH2_Eng (for English version of Windows®)
 CD_FluidEXL_Graphics_LibH2 (for German version of Windows)

into the folder you have chosen for the installation of FluidEXL^{Graphics} (the standard being

C:\Program Files\FuildEXL_Graphics_Eng (for English version of Windows)
 C:\Programme\FuildEXL_Graphics (for German version of Windows)

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

FluidEXL_Graphics_Eng.xla (for English version of Windows)
 FluidEXL_Graphics.xla (for German version of Windows)
 LibH2.dll
 LibH2.hlp.

Now it is possible to select the property functions of the DLL library "Hydrogen LibH2" for Hydrogen directly from Excel (see section 2.5 on page 2/19).

2.3 The FluidEXL^{Graphics} Help System

As mentioned earlier, FluidEXL^{Graphics} also provides detailed online help functions. If you are running Windows Vista or Windows 7, please note the paragraph

"Using the FluidEXL^{Graphics} Online-Help in Windows Vista or Windows 7."

For general information in Excel®:

- Click on "?" and then "Help" in the FluidEXL^{Graphics} menu bar.

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

- Click "Calculate" in the FluidEXL^{Graphics} menu bar.
- Select the "Hydrogen LibH2" library under "Or select a category:" in the "Insert Function" window which will appear.
- Click the "Help on this function" button in the lower left-hand edge of the "Insert Function" window.
- If the "Office Assistant" is active, first double-click "Help on this feature" and in the next menu click "Help on selected function".

If the LibH2.hlp function help cannot be found, confirm the question whether you want to look

for it yourself with "Yes". Click on the LibH2.hlp file in the installation menu of FluidEXL *Graphics* in the window which is opened, in the standard case

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows®)

C:\Programme\FluidEXL_Graphics (for German version of Windows),

and click "Yes" in order to complete the search.

Using the FluidEXL *Graphics* Online Help in Windows Vista or Windows 7

If you are running Windows Vista or Windows 7 on your computer, you might not be able to open Help files. To view these files you have to install the Microsoft® Windows Help program which is provided by Microsoft®. Please carry out the following steps in order to download and install the Windows Help program.

Open Microsoft Internet Explorer® and go to the following address:

<http://support.microsoft.com/kb/917607/>

You will see the following web page:

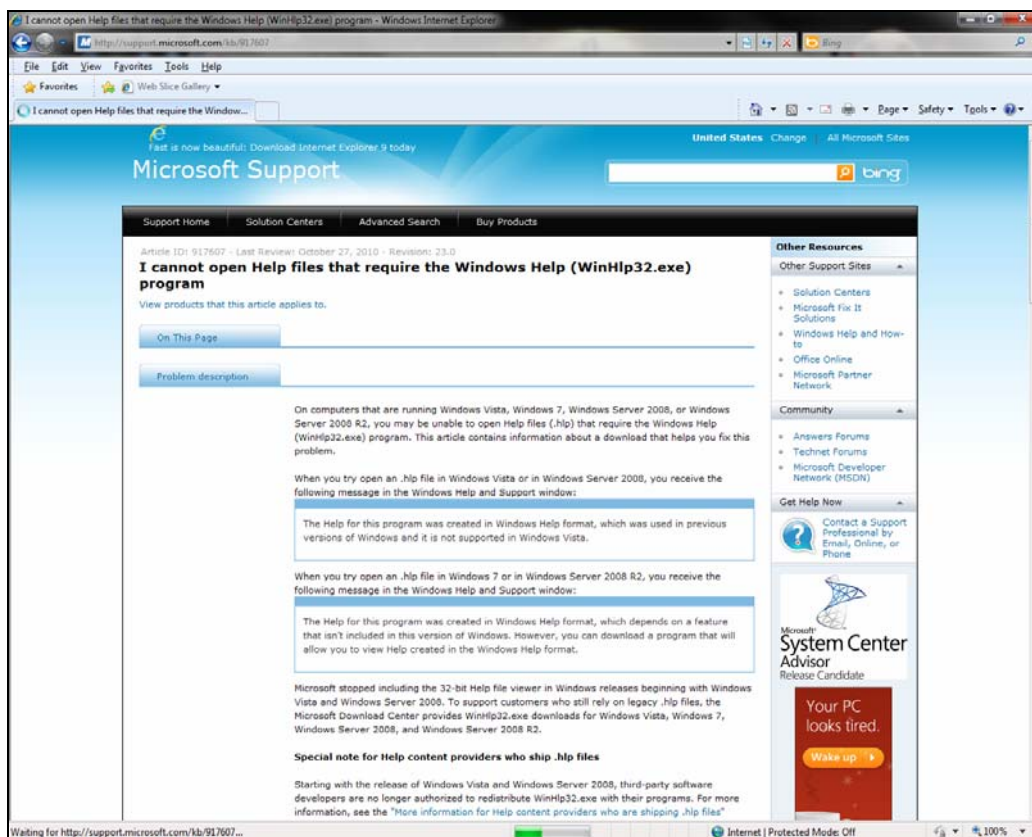


Figure 2.12: Microsoft® Support web page

Scroll down until you see the headline "Resolution." Here you can see the bold hint:

"Download the appropriate version of Windows Help program (WinHlp32.exe), depending on the operating system that you are using."

The following description relates to Windows® 7. The procedure is analogous for Windows® Vista.

Click on the link "Windows Help program (WinHlp32.exe) for Windows 7" (see Figure 2.13).

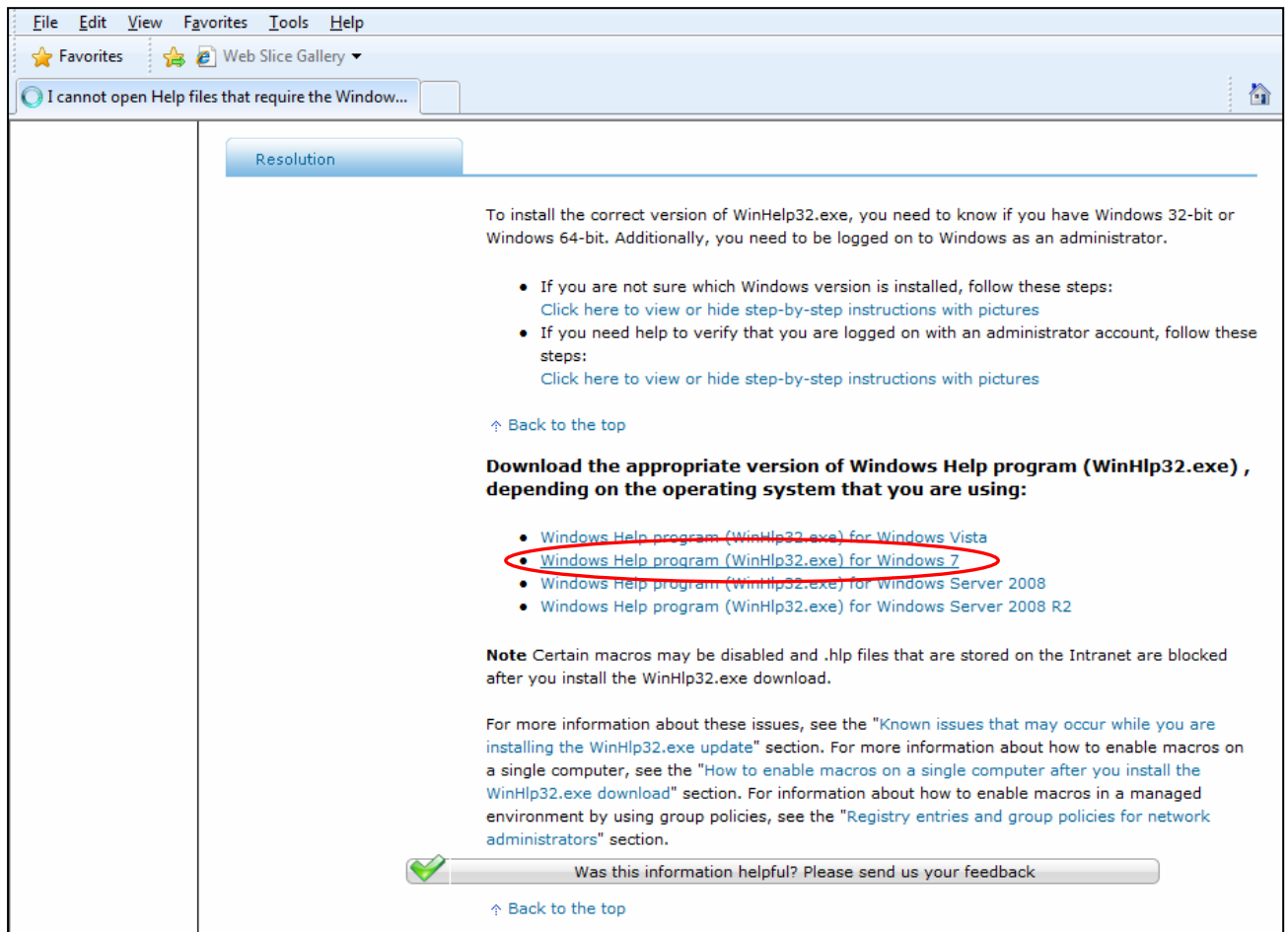


Figure 2.13: Selecting your Windows version

You will be forwarded to the Microsoft Download Center where you can download the Microsoft Windows Help program.

First, a validation of your Windows License is required.

To do this click on the "Continue" button (see Figure 2.14).

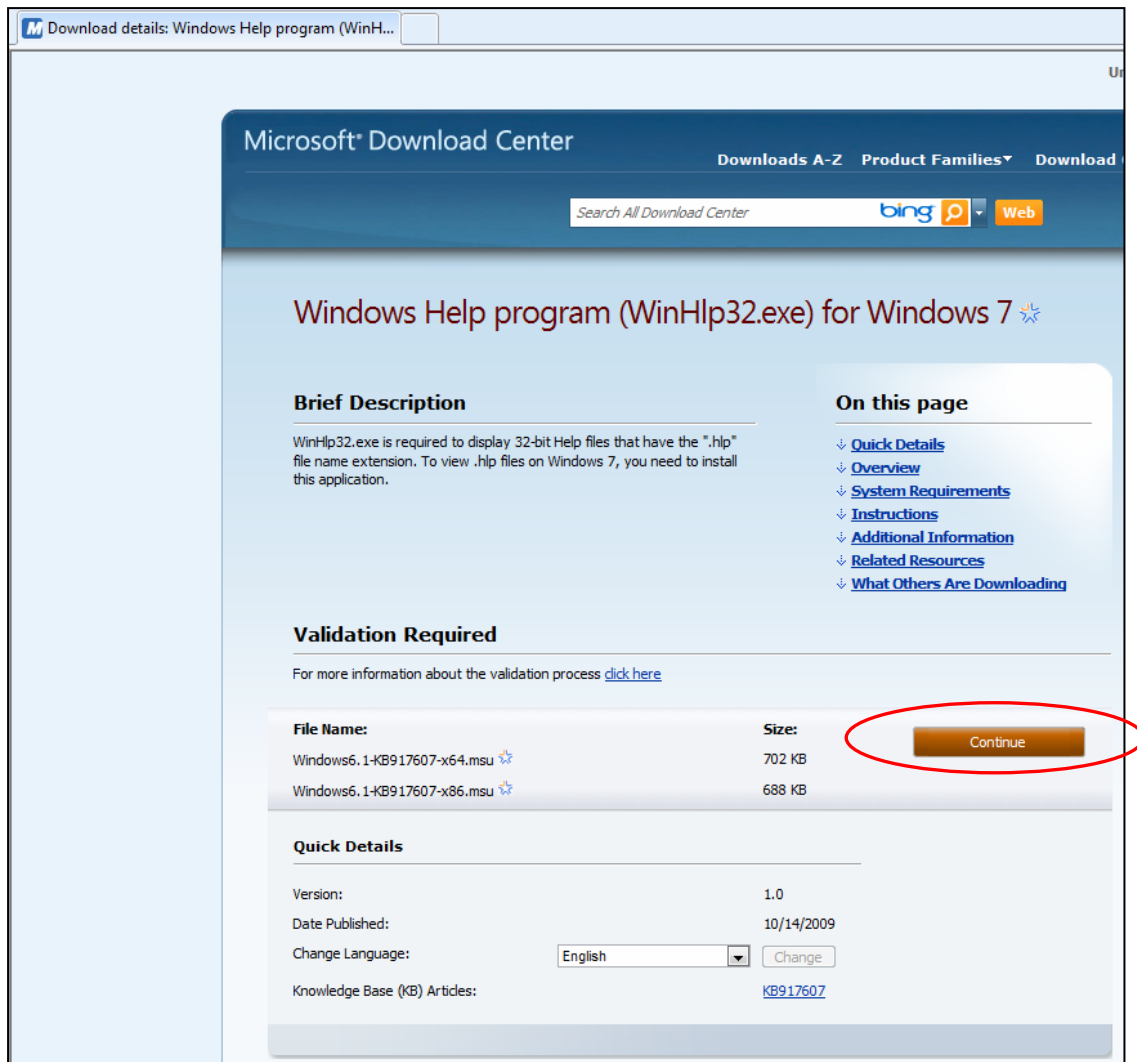


Figure 2.14: Microsoft® Download Center

You will be forwarded to a web page with instructions on how to install the Genuine Windows Validation Component.

At the top of your Windows Internet Explorer you will see a yellow information bar. Right-click this bar and select "Install ActiveX Control" in the context menu (see Figure 2.15).

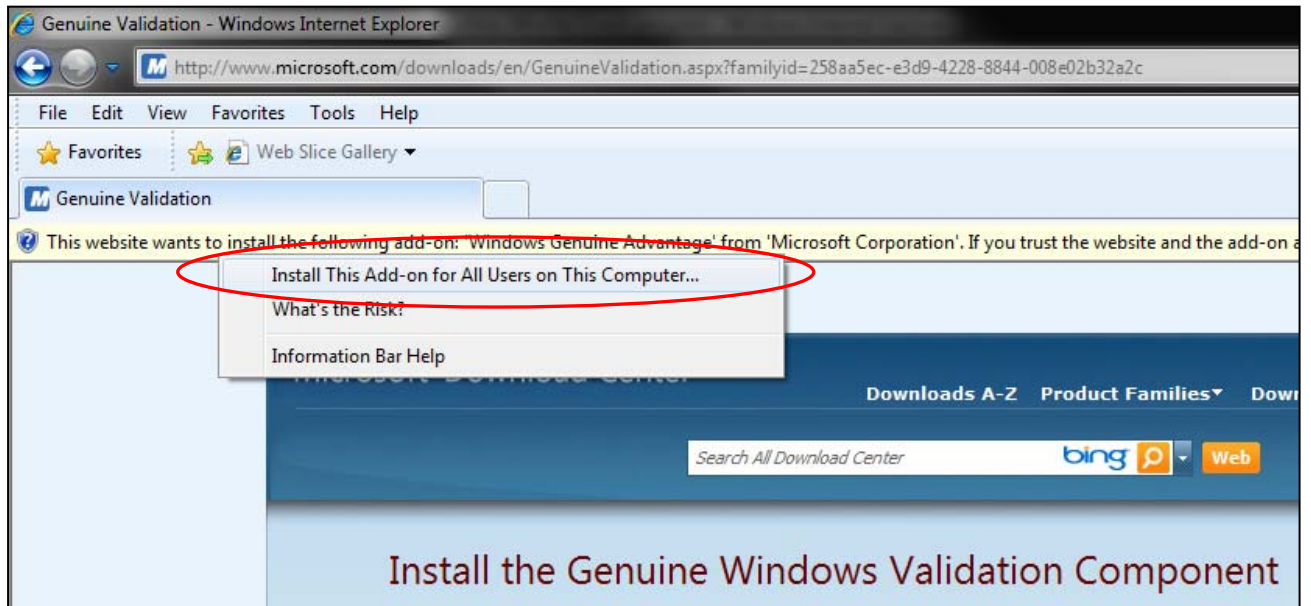


Figure 2.15: Installing the Genuine Windows Validation Component

A dialog window appears in which you will be asked if you want to install the software. Click the "Install" button to continue (see Figure 2.16).

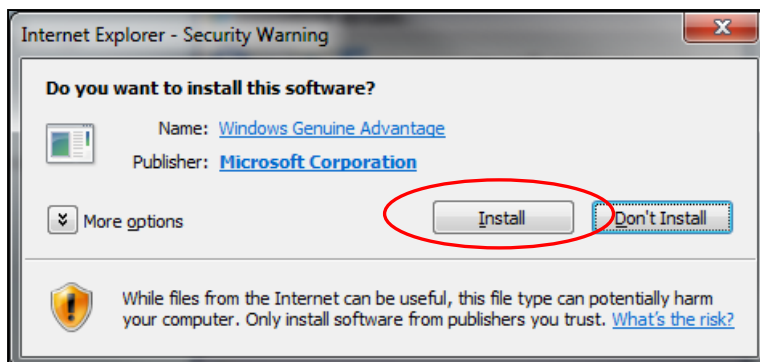


Figure 2.16: Internet Explorer – Security Warning

After the validation has been carried out you will be able to download the appropriate version of Windows Help program (see Figure 2.17).

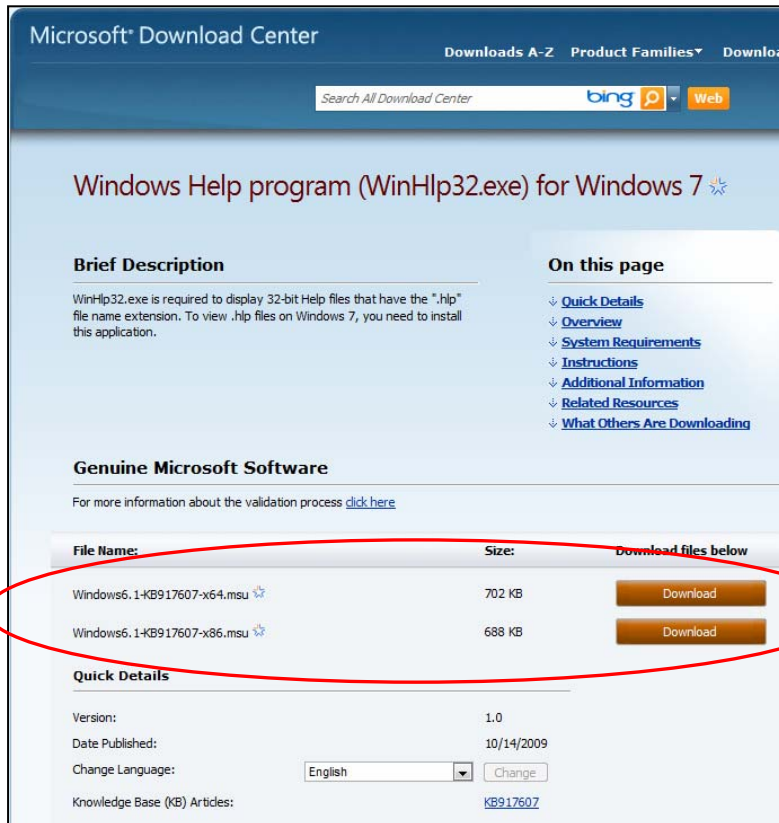


Figure 2.17: Downloading the Windows Help program

To download and install the correct file you need to know which Windows version (32-bit or 64-bit) you are running on your computer.

If you are running a 64-bit operating system, please download the file
Windows6.1-KB917607-x64.msu.

If you are running a 32-bit operating system, please download the file
Windows6.1-KB917607-x86.msu.

In order to run the installation of the Windows Help program double-click the file you have just downloaded on your computer:

Windows6.1-KB917607-x64.msu (for 64-bit operating system)

Windows6.1-KB917607-x86.msu. (for 32-bit operating system).

Installation starts with a window searching for updates on your computer. After the program has finished searching you may see the following window.

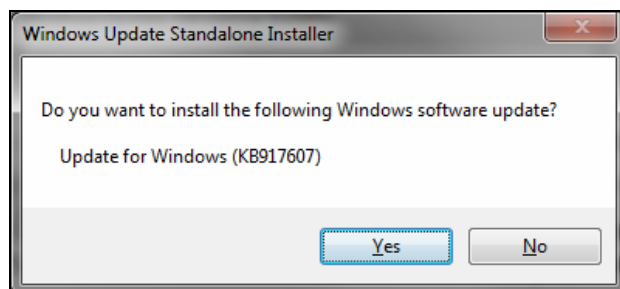


Figure 2.18: Windows Update Standalone Installer

In this case, the installation can be continued by clicking the "Yes" button.

(If you have already installed this update, you will see the message "Update for Windows (KB917607) is already installed on this computer.")

In the next window you have to accept the Microsoft license terms before installing the update by clicking on "I Accept" (see Figure 2.19)

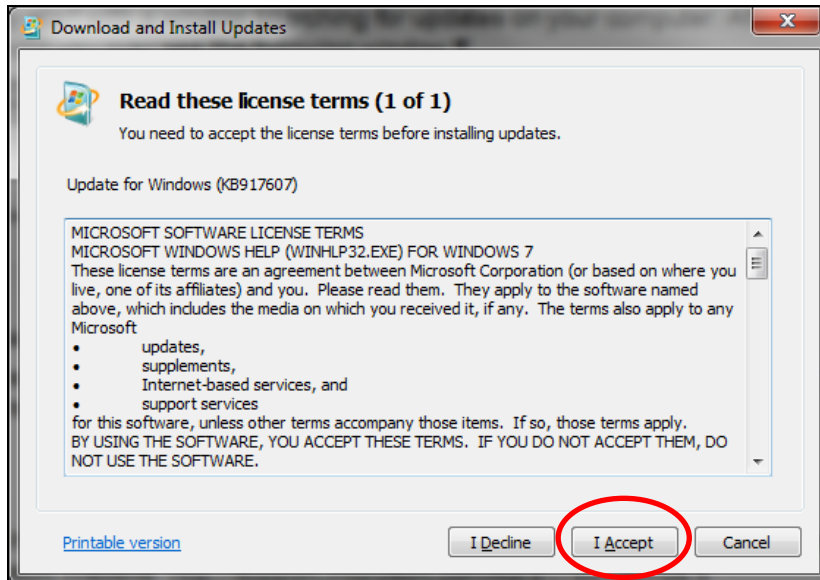


Figure 2.19: Windows License Terms

Installation starts once you have clicked the "I Accept" button (see Figure 2.20).

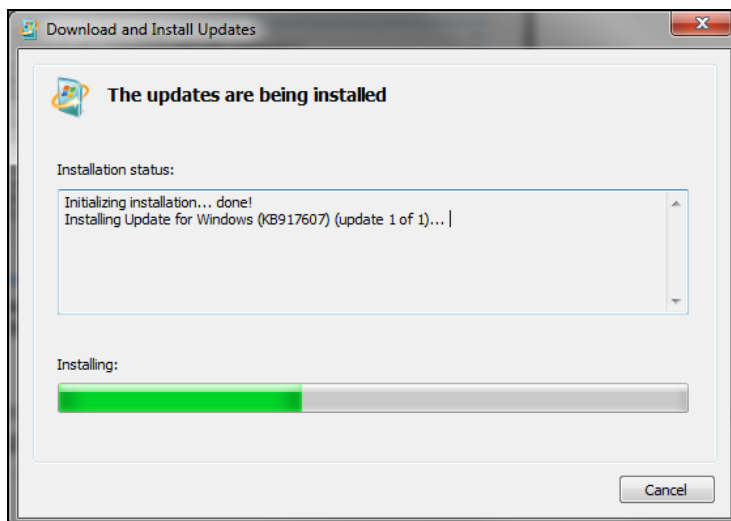


Figure 2.20: Installation process

After the Windows Help program has been installed, the notification "Installation complete" will appear. Confirm this by clicking the "Close" button.

The installation of the Windows Help program has been completed and you will now be able to open the Help files.

2.4 Licensing the LibH2 Property Library

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

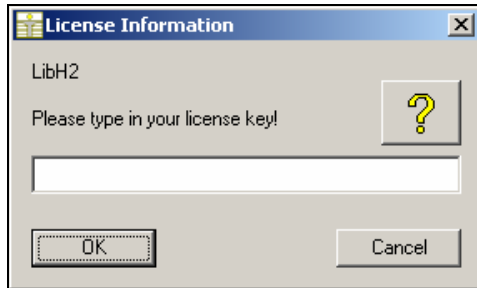


Figure 2.21: "License Information" window

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



Figure 2.22 "Help" window

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

The "License Information" window will appear every time you start Excel unless you uninstall FluidEXL^{Graphics} according to the description in section 2.6 of this User's Guide.

Should you not wish to license the LibH2 property library, you have to delete the files

LibH2.dll
LibH2.hlp

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

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows))

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

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

Now we will calculate, step by step, the specific enthalpy h as a function of pressure p , temperature t , and vapor fraction x , using FluidEXL *Graphics*. Here we use a calculation in the single phase region as example to explain how the specific enthalpy h is calculated for H₂-Normal and H₂-Para. Please carry out the following steps:

- Enter the value for p in bar in a cell
(Range of validity: $p = 0.001 \text{ bar} \dots 1210 \text{ bar}$)

⇒ e. g.: Enter the value 10 for p into cell A3

- Enter the value for t in °C in a cell
(Range of validity: $t = t_{\text{mel}} \text{ or } t_{\text{min}} \dots 126.85^\circ\text{C}$)

⇒ e. g.: Enter the value 25 for t into cell B3

- Enter the value for x in kg saturated steam/kg wet steam into a cell

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

Single-phase region

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

Wet-steam region

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

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

If p and t and x are entered as given values, the program considers p and t to be appropriate to represent the vapor pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in -1000 .

Vapor pressure curve of H₂-Para:

$$\begin{aligned} t_t &= -259.35^\circ\text{C} \dots t_c = 240.212^\circ\text{C} \\ p_t &= 0.0703991859 \text{ bar} \dots p_c = 12.837878 \text{ bar} \end{aligned}$$

Vapor pressure curve of H₂-Normal:

$$\begin{aligned} t_t &= -259.193^\circ\text{C} \dots t_c = 240.212^\circ\text{C} \\ p_t &= 0.0770478607 \text{ bar} \dots p_c = 12.837878 \text{ bar} \end{aligned}$$

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

- Enter a value for NP into a cell

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

In case H₂-Para is given, you have to enter the value NP = 0.

⇒ e.g.: Enter the value 1 for H₂-Normal into cell D2

⇒ e.g.: Enter the value 0 for H₂-Para into cell D3

The following steps have to be completed for the different forms of Hydrogen, H₂-Normal und H₂-Para. In order to obtain a better view, the results of the calculated enthalpy h in kJ/kg are being written next to the corresponding cells of the parameter NP.

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

⇒ e.g.: Click cell E3

- Click "Calculate" in the menu bar of FluidEXL *Graphics*
The "Insert Function" menu, which is shown in Figure 2.23, pops up.

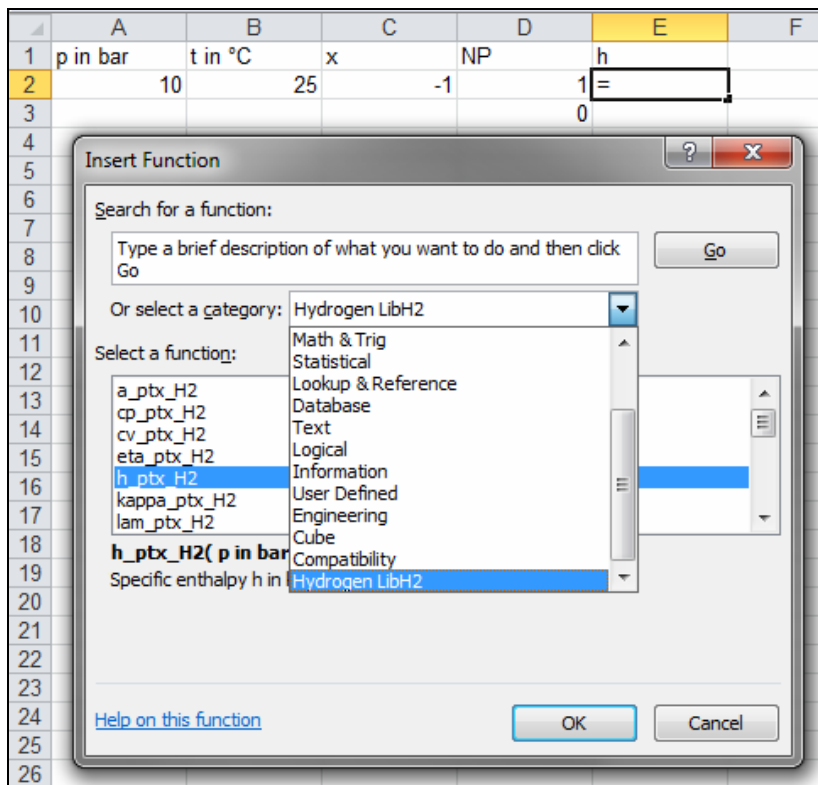


Figure 2.23: Choice of library and function name

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

The menu shown in Figure 2.24 will now appear.

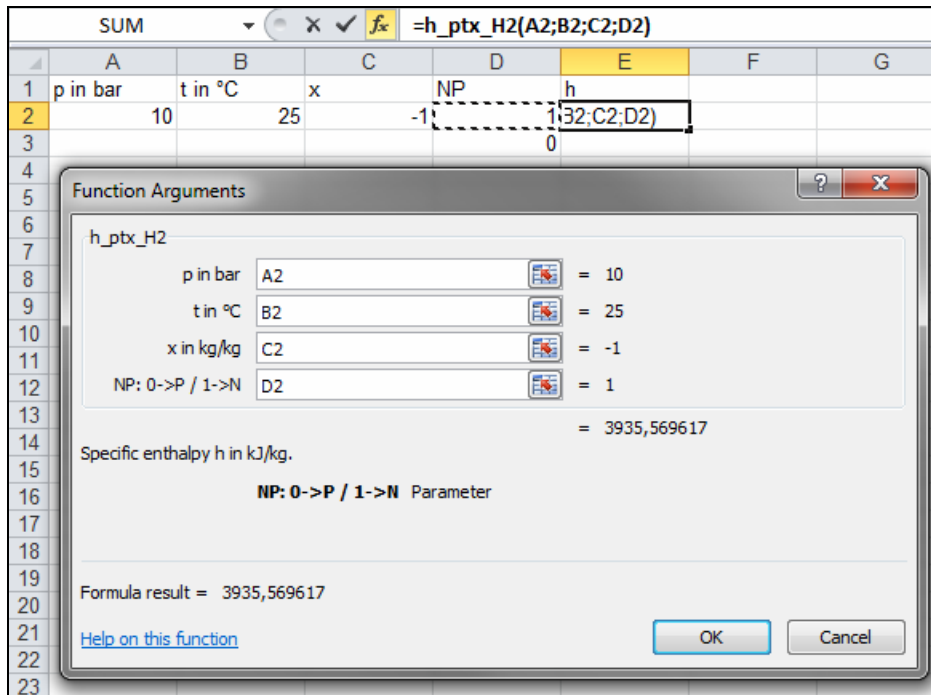


Figure 2.24: Enter the given values for the property calculation

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

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

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

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

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

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

Hint:

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

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

Number formats

Number formats can be chosen in FluidEXL *Graphics* directly in advance.

Changes can be made as follows:

- Click on the cell or mark the cells to be formatted
(If you choose an empty cell, the new format will be applied after a value has been entered.)
- Click "Number Format" in the menu bar of FluidEXL *Graphics*.
- Click on the desired format under "Format":

"STD - Standard"	- non-significant zeros behind the decimal point will not be shown
"FIX – Fix Number of Digits"	- All decimal digits will be shown, also significant zeros
"SCI – Scientific Format"	- The number will be shown in exponential form and the decimal places.
- Enter the number of decimal places next to "Number of Decimal Places" into the corresponding window
- Confirm your selection by clicking the "OK" button

The table below shows the different displayed formats for the number 1.230 with adjusted 3 decimal places:

STD	1.23
FIX	1.230
SCI	1.230E+00

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

2.6 Removing FluidEXL *Graphics*

Should you wish to remove only the LibH2 library, delete the files

LibH2.dll

LibH2.hlp

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

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

C:\Programme\FuildEXL_Graphics (for German version of Windows)

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

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

To remove FluidEXL *Graphics* completely, proceed as follows: First the registration of

FluidEXL_Graphics_Eng.xla (for English version of Windows)

FluidEXL_Graphics.xla (for German version of Windows)

has to be cancelled in Excel®.

In order to do that, click "Tools" in the upper menu bar of Excel and here "Add-Ins...". Untick the box on the left-hand side of

"FluidEXL Graphics Eng" (for English version of Windows)

"FluidEXL Graphics" (for German version of Windows)

in the window that appears and click the "OK" button. The additional menu bar of FluidEXL *Graphics* disappears from the upper part of the Excel window. Afterwards, we recommend closing Excel.

If the FluidEXL *Graphics* menu bar does not disappear, take the following steps:

Click "View" in the upper menu bar of Excel, then "Toolbars" and then "Customize..." in the list box which appears.

"FluidEXL Graphics Eng" (for English version of Windows)

"FluidEXL Graphics" (for German version of Windows)

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

Within the next step delete the files

LibH2.dll

LibH2.hlp

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

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

C:\Programme\FuildEXL_Graphics (for German version of Windows),

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

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

"FluidEXL Graphics Eng" (for English version of Windows)

"FluidEXL Graphics" (for German version of Windows)

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

Unregistering FluidEXL *Graphics* as Add-In in Excel® 2007 (or later versions)

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

- Click the Windows Office® button in the upper left corner of Excel
- Click on the "Excel Options" button in the menu which appears

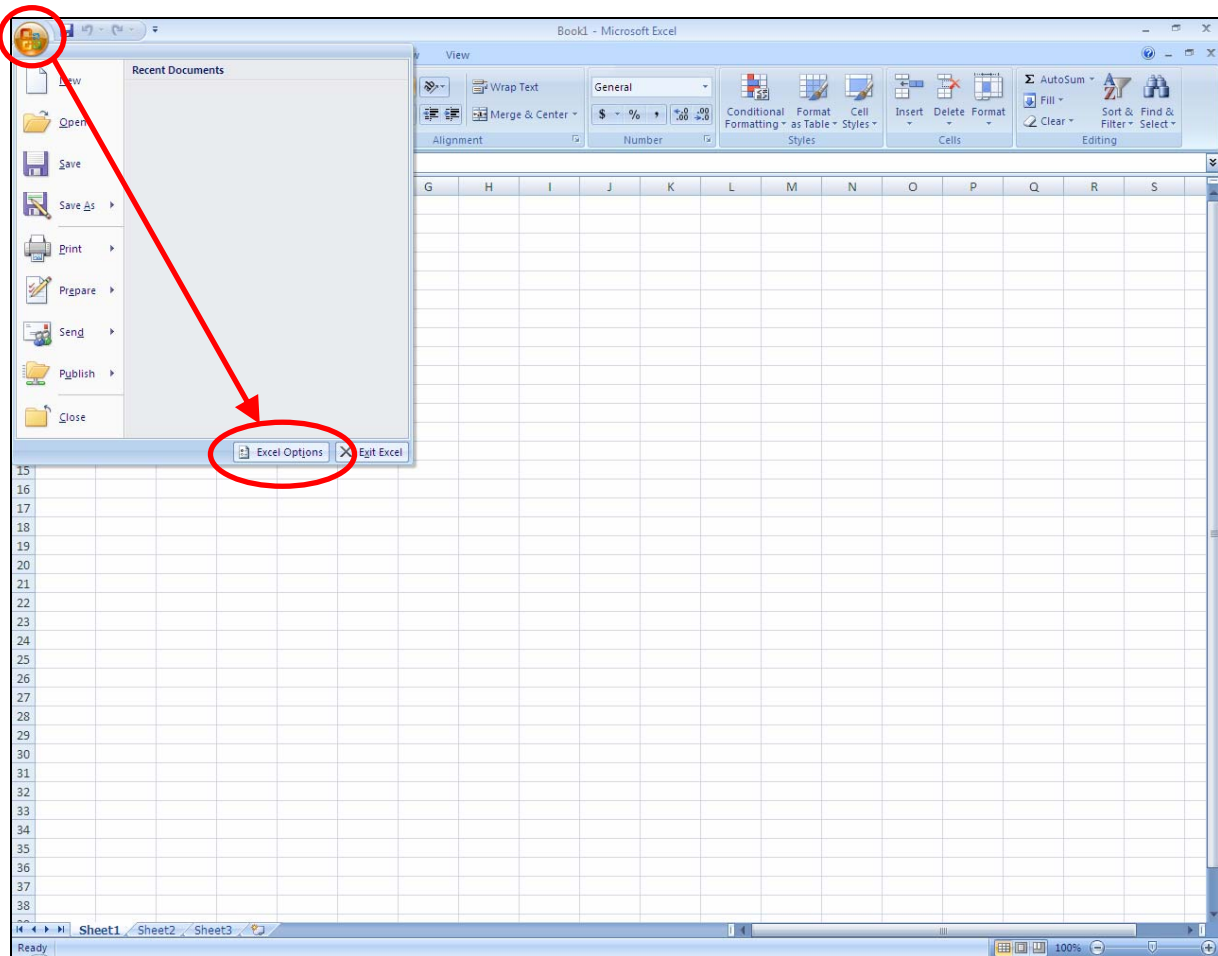


Figure 2.25: Unregistering FluidEXL *Graphics* as Add-In in Excel® 2007

- Click on "Add-Ins" in the next menu

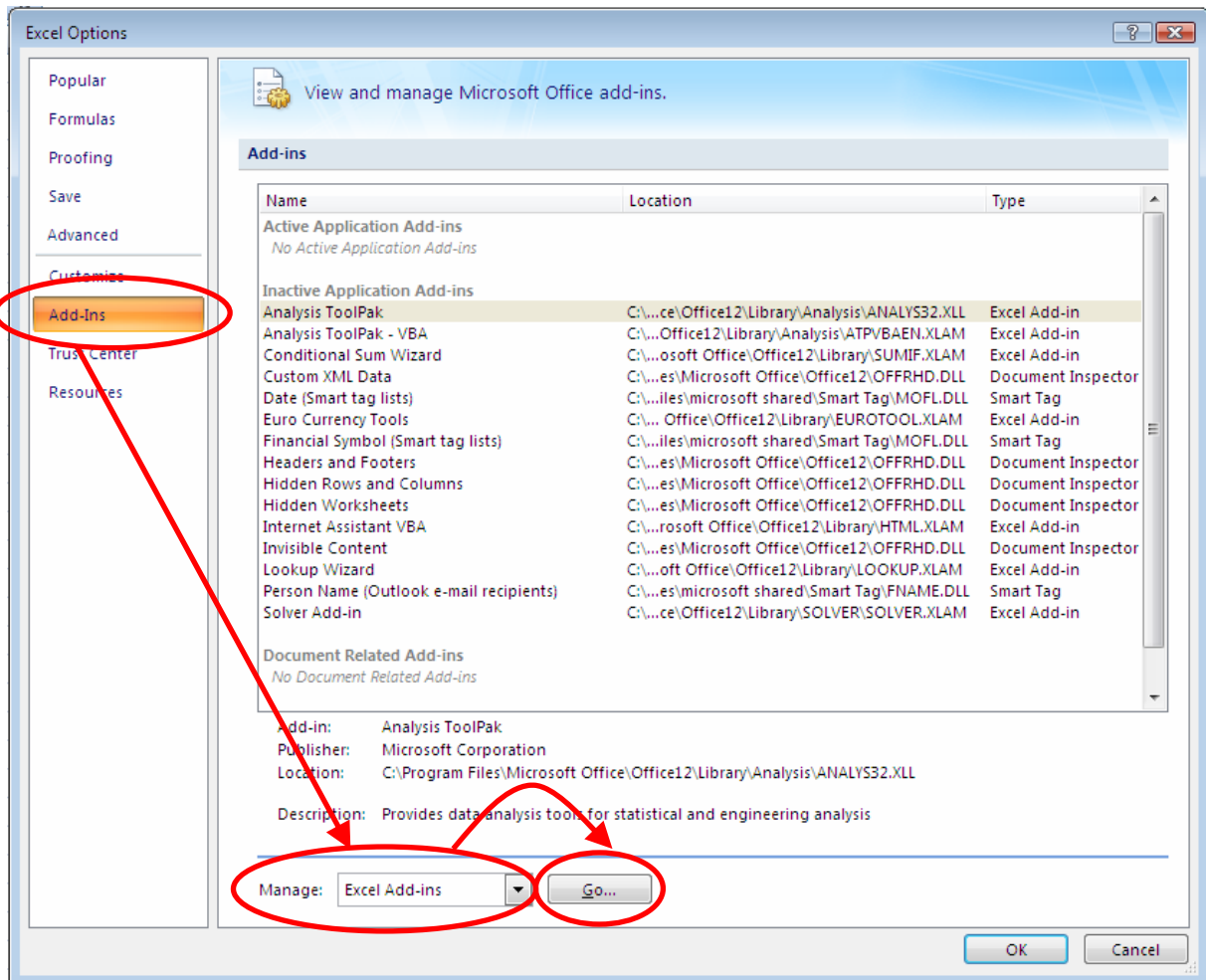


Figure 2.26: Dialog window "Add-Ins"

- If it is not shown in the list automatically, chose and click "Excel Add-ins" next to "Manage:" in the lower area of the menu
- Afterwards click the "Go..." button
- Remove the checkmark in front of
 "FluidEXL Graphics Eng" (for English version of Windows)
 "FluidEXL Graphics" (for German version of Windows)
 in the window which now appears. Click the "OK" button to confirm your entry.

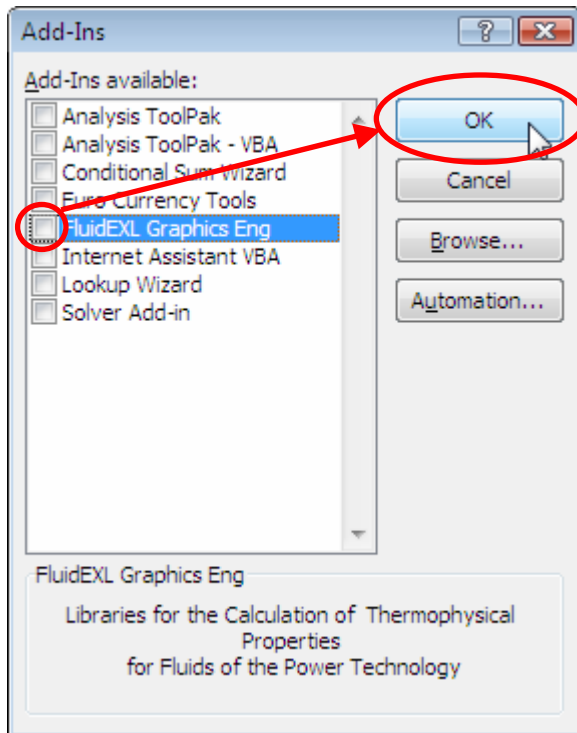


Figure 2.27: Dialog window "Add-Ins"

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

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

In the list box of the "Add or Remove Programs" window that appears, select

"FluidEXL Graphics Eng" (for English version of Windows)

"FluidEXL Graphics" (for German version of Windows)

by clicking on it and then clicking the "Add/Remove..." button.

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

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

Answer the question of whether all shared components should be removed with "Yes to All."

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

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

3. Program Documentation

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

Function Name: **a_ptx_H2**

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

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

Input values:

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x (kg of saturated steam)/(kg wet steam)
NP – Calculation parameter for choosing H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

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

H₂ – Normal (NP = 1):

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

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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

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

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

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

Boiling and dew curve:

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

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

Results for wrong input values

Result **APTXXH2 = -1000, A = -1000** or **a_ptx_H2 = -1000** for Input values:

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212^\circ\text{C}$ or $t < -259.35^\circ\text{C}$
 at $t = -1000$ and $p > 12.837878$ bar or $p < 0.0770478607$ bar or
 at $p > 12.837878$ bar or $p < 0.0770478607$ bar and
 $t > -240.212^\circ\text{C}$ or $t < -259.193^\circ\text{C}$

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

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

Boiling or dew curve:

at $p = -1000$ and $t > -240.212^\circ\text{C}$ or $t < -259.35^\circ\text{C}$
 at $t = -1000$ and $p > 12.837878$ bar or $p < 0.0703991859$ bar or
 at $p > 12.837878$ bar or $p < 0.0703991859$ bar and
 $t > -240.212^\circ\text{C}$ or $t < -259.35^\circ\text{C}$

References: [22], [23]

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

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

Input values:

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x (kg of saturated steam)/(kg wet steam)
NP – Calculation parameter for choosing H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

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

H₂ – Normal (NP = 1):

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

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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

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

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

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

Boiling and dew curve:

H₂ – Normal (NP = 1): Temperature range from $t_t = -259.193$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

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H₂ – Para (NP = 0): Temperature range from $t_i = -259.35$ °C to $t_c = -240.212$ °C
Pressure range from $p_i = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

H₂-Normal (NP = 1):

Single phase region:

$$(x = -1)$$

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

Boiling or dew curve:

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

H₂-Para (NP = 0):

Single phase region:

$$(x = -1)$$
$$\begin{aligned}
 & p > 1210 \text{ bar or } p < 0.001 \text{ bar or} \\
 & t > 126.85 \text{ }^{\circ}\text{C or } t < t_{\text{mel}}(p) \text{ or } t < t(p, \rho_{\text{max}}) \text{ at } p \geq p_t = 0.0703991859 \text{ bar or} \\
 & t < t_{\text{trip}} = -259.35 \text{ }^{\circ}\text{C at } p < p_t = 0.0703991859 \text{ bar} \\
 & \rho_{\text{max}} = 44.0 \text{ mol/l}
 \end{aligned}$$

Boiling or dew curve:

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

References: [22]

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

Function Name: **cv_ptx_H2**

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

Subroutine with parameter: **INTEGER*4 FUNCTION C_CVPTXH2(CV,P,T,X,NP)**
for call from DLL **REAL*8 CV,P,T,X,NP**

Input values:

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x (kg of saturated steam)/(kg wet steam)
NP – Calculation parameter for choosing H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

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

H₂ – Normal (NP = 1):

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

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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

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

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

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

Boiling and dew curve:

H₂ – Normal (NP = 1): Temperature range from $t_t = -259.193$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H₂ – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

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

Boiling or dew curve:

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

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

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

Boiling or dew curve:

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

References: [22]

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

Function Name: **eta_ptx_H2**

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

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

Input values:

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x (kg of saturated steam)/(kg wet steam)
NP – Calculation parameter for choosing H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

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

H₂ – Normal (NP = 1):

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

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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

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

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

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

Boiling and dew curve:

H₂ – Normal (NP = 1): Temperature range from $t_t = -259.193$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H₂ – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

References: [22], [23]

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

Function Name: **h_ptx_H2**

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

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

Input values:

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x (kg of saturated steam)/(kg wet steam)
NP – Calculation parameter for choosing H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

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

H₂ – Normal (NP = 1):

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

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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

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

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

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

Boiling and dew curve:

H₂ – Normal (NP = 1): Temperature range from $t_t = -259.193$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H₂ – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

References: [22]

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

Function Name: **kappa_ptx_H2**
 Subroutine with function value: **REAL*8 FUNCTION KAPPTXH2(P,T,X,NP)**
 for call from Fortran **REAL*8 P,T,X,NP**
 Subroutine with parameter: **INTEGER*4 FUNCTION C_KAPPTXH2(KAP,P,T,X,NP)**
 for call from DLL **REAL*8 KAP,P,T,X,NP**

Input values:

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x (kg of saturated steam)/(kg wet steam)
NP – Calculation parameter for choosing H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

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

H₂ – Normal (NP = 1):

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

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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

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

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

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

Boiling and dew curve:

H₂ – Normal (NP = 1): Temperature range from $t_t = -259.193$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H₂ – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

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

Boiling or dew curve:

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

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

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

Boiling or dew curve:

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

References: [22]

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

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

Input values:

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x (kg of saturated steam)/(kg wet steam)
NP – Calculation parameter for choosing H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

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

H₂ – Normal (NP = 1):
 from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193$ °C to 126.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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

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

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

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

Boiling and dew curve:

H₂ – Normal (NP = 1): Temperature range from $t_t = -259.193$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar
 H₂ – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

References: [22], [23]

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

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

Input values:

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x (kg of saturated steam)/(kg wet steam)
NP – Calculation parameter for choosing H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

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

H₂ – Normal (NP = 1):

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

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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

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

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

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

Boiling and dew curve:

H₂ – Normal (NP = 1): Temperature range from $t_t = -259.193$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar
 H₂ – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

References: [22], [23]

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

Function Name: **pmel_t_H2**

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

Subroutine with parameter:
for call from DLL **INTEGER*4 FUNCTION C_PMELH2(PMEL,T,NP)**
REAL*8 PMEL, T,NP

Input values:

T - Temperature t in °C

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

Result

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

Range of validity

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

Results for wrong input values

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

NP $\neq$ 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 H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

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

H₂ – Normal (NP = 1):

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

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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

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

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

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

Boiling and dew curve:

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

H₂ – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

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

Boiling or dew curve:

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

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

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

Boiling or dew curve:

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

References: [22]

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 H₂ – Normal or H₂ – Para

Result

PSTH2, PS or ps_t_H2 – Vapor pressure p_s in bar

Range of validity

Temperature range:

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

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

Results for wrong input values

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

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

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

References: [22], [23]

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

Function Name: **rho_ptx_H2**

Subroutine with function value:
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 H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

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

H₂ – Normal (NP = 1):

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

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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

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

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

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

Boiling and dew curve:

H₂ – Normal (NP = 1): Temperature range from $t_t = -259.193$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H₂ – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

References: [22]

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

Function Name: **s_ptx_H2**

Subroutine with function value:
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 H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

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

H₂ – Normal (NP = 1):

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

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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

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

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

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

Boiling and dew curve:

H₂ – Normal (NP = 1): Temperature range from $t_t = -259.193$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H₂ – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

References: [22]

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

Function Name: **t_ph_H2**

Subroutine with function value:
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 H₂ – Normal or H₂ – Para

Result

TPHH2, T or t_ph_H2 - Temperature t in °C

Range of validity

Temperature range:

H₂ – Para (NP = 0):

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

H₂ – Normal (NP = 1):

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

Pressure range: from 0.001 bar to 1210 bar

Details on the vapor fraction x and wet steam

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

Wet steam region:

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

H₂ – Para (NP = 0): Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

H₂-Normal (NP = 1):

Single phase region:

($x = - 1$)

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

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

Boiling or dew curve:

at $p > 12.837878 \text{ bar}$ or $p < 0.0770478607 \text{ bar}$ or
 calculation result $t > -240.212 \text{ °C}$ or $t < -259.193 \text{ °C}$

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

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

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

Boiling or dew curve:

at $p > 12.837878 \text{ bar}$ or $p < 0.0703991859 \text{ bar}$ or
 calculation result $t > -240.212 \text{ °C}$ or $t < -259.35 \text{ °C}$

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 H₂ – Normal or H₂ – Para

Result

TPSH2, T or t_ps_H2 - Temperature t in °C

Range of validity

Temperature range:

H₂ – Para (NP = 0):

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

H₂ – Normal (NP = 1):

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

Pressure range: from 0.001 bar to 1210 bar

Details on the vapor fraction x and wet steam

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

Wet steam region:

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

H₂ – Para (NP = 0): Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

H₂-Normal (NP = 1):

Single phase region:

($x = - 1$)

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

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

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

Boiling or dew curve:

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

$$\text{calculation result } t > -240.212 \text{ }^{\circ}\text{C or } t < -259.193 \text{ }^{\circ}\text{C}$$

H₂-Para (NP = 0):

Single phase region:

$$(x = -1)$$

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

$$\text{at the calculation result } t > 126.85 \text{ }^{\circ}\text{C or}$$

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

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

Boiling or dew curve:

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

$$\text{calculation result } t > -240.212 \text{ }^{\circ}\text{C or } t < -259.35 \text{ }^{\circ}\text{C}$$

References: [22]

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

Function Name:	ts_p_H2
Subroutine with function value: for call from Fortran	REAL*8 FUNCTION TSPH2(P,NP) REAL*8 P,NP
Subroutine with parameter: for call from DLL	INTEGER*4 FUNCTION C_TSPH2(TS,P,NP) REAL*8 TS,P,NP

Input values:

P - Pressure p in bar

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

Result

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

Range of validity

Pressure range:

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

H₂ – Para (NP = 0): Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

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

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

References: [22], [23]

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

Function Name: **tmel_p_H2**

Subroutine with function value:
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 H₂ – Normal or H₂ – Para

Result

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

Range of validity

Pressure range: from 0.0703991859 bar to 1210 bar

Results for wrong input values

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

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 H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

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

H₂ – Normal (NP = 1):

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

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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

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

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

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

Boiling and dew curve:

H₂ – Normal (NP = 1): Temperature range from $t_t = -259.193$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H₂ – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

References: [22]

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

Function Name: **v_ptx_H2**

Subroutine with function value:
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 H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

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

H₂ – Normal (NP = 1):
 from $t_{\text{mel}}(p)$ or $t_{\text{min}} = t(p, \rho_{\text{max}})$ to 126.85°C at $p \geq p_t = 0.0770478607$ bar,
 with $\rho_{\text{max}} = 38.148$ mol/l ($v_{\text{min}} = 0.0130032114$ m³/kg)
 from $t_{\text{trip}} = -259.193$ °C to 126.85°C at $p \leq p_t = 0.0770478607$ bar

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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

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

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

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

Boiling and dew curve:

H₂ – Normal (NP = 1): Temperature range from $t_t = -259.193$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H₂ – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

References: [22]

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

Function Name: **w_ptx_H2**

Subroutine with function value:
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 H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

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

H₂ – Normal (NP = 1):

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

Pressure range: from 0.001 bar to 1210 bar

Details on wet steam and the vapor fraction x

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

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

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

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

Boiling and dew curve:

H₂ – Normal (NP = 1): Temperature range from $t_t = -259.193$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0770478607$ bar to $p_c = 12.837878$ bar

H₂ – Para (NP = 0): Temperature range from $t_t = -259.35$ °C to $t_c = -240.212$ °C
 Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

H₂-Normal (NP = 1):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

H₂-Para (NP = 0):

Single phase region:

($x = -1$)

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

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

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

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

Boiling or dew curve:

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

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

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

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

References: [22]

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

Function Name: **x_ph_H2**

Subroutine with function value:
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 H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

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

H₂ – Normal (NP = 1):

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

Pressure range: from 0.001 bar to 1210 bar

Details on the calculation of wet steam

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

Wet steam region:

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

H₂ – Para (NP = 0): Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

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

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

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

References: [22]

Zittau/Goerlitz University of Applied Sciences, Department of Technical Thermodynamics, Professor H.-J. Kretschmar, Dr. I. Stoecker

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 H₂ – Normal or H₂ – Para

Result

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

Range of validity

Temperature range:

H₂ – Para (NP = 0):

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

H₂ – Normal (NP = 1):

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

Pressure range: from 0.001 bar to 1210 bar

Details on the calculation of wet steam

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

Wet steam region:

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

H₂ – Para (NP = 0): Pressure range from $p_t = 0.0703991859$ bar to $p_c = 12.837878$ bar

Results for wrong input values

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

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

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

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

References: [22]

Zittau/Goerlitz University of Applied Sciences, Department of Technical Thermodynamics, Professor H.-J. Kretschmar, Dr. I. Stoecker



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

Water and Steam

Library LibIF97

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

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:
 CO_2 - Span and Wagner O_2 - Schmidt and Wagner
 H_2O - IAPWS-95 Ar - Tegeler et al.
 N_2 - Span et al.
 and of the ideal gases:
 SO_2 , CO, Ne (Scientific Formulation of Bückner et al.)
 Consideration of:
 Dissociation from VDI 4670 and Poynting effect

Humid Air

Library LibHuAir

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

Carbon Dioxide including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1994)

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

Dry Air including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Nitrogen

Library LibN2

Formulation of Span et al. (2000)

Ice

Library LibICE

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

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Hydrogen

Library LibH2

Formulation of Leachman et al. (2007)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth (1995)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bückner et al. (2003)

n-Butane

Library LibButane_n

Formulation of Bückner et al. (2003)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

Water/Lithium Bromide Mixtures

Library LibWaLi

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

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

$\text{C}_2\text{H}_6\text{O}_2$	Ethylene glycol
$\text{C}_3\text{H}_8\text{O}_2$	Propylene glycol
$\text{C}_2\text{H}_5\text{OH}$	Ethyl alcohol
CH_3OH	Methyl alcohol
$\text{C}_3\text{H}_8\text{O}_3$	Glycerol
K_2CO_3	Potassium carbonate
CaCl_2	Calcium chloride
MgCl_2	Magnesium chloride
NaCl	Sodium chloride
$\text{C}_2\text{H}_3\text{KO}_2$	Potassium acetate

 Formulation of the International Institute of Refrigeration (1997)

Siloxanes as ORC Working Fluids

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

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Propane

Library LibPropane

Formulation of Lemmon et al. (2007)

Methanol

Library LibCH3OH

Formulation of de Reuck and Craven (1993)

Ethanol

Library LibC2H5OH

Formulation of Schroeder et al. (2012)

Helium

Library LibHe

Formulation of Arp et al. (1998)

Hydrocarbons

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

Dinitrogen monoxide N_2O **Library LibN2O**

Sulfur dioxide SO_2 **Library LibSO2**

Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

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Fax.: +49-3583-61-1846

The following thermodynamic and transport properties can be calculated^a:

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

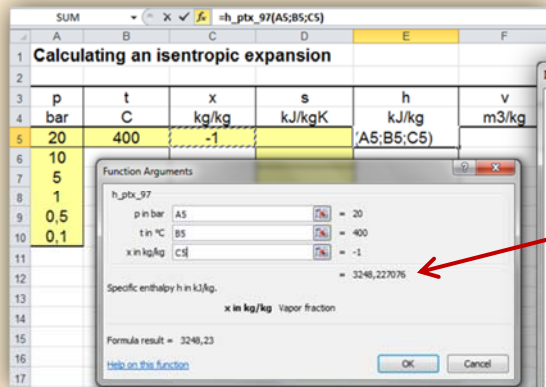
- Partial derivatives can be calculated.

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

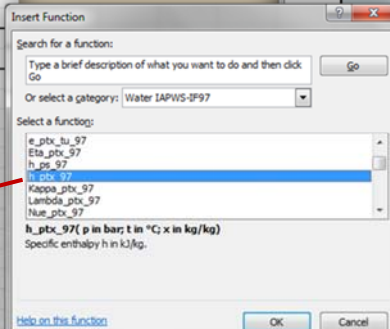


Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

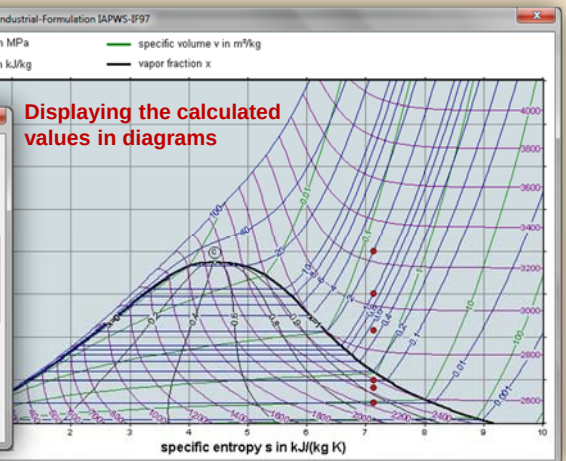
Add-In FluidEXL^{Graphics} for Excel[®]



Choosing a property library and a function



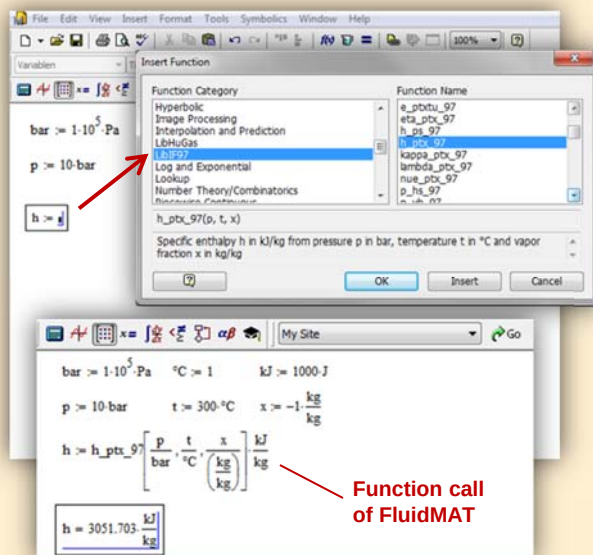
Displaying the calculated values in diagrams



Menu for the input of given property values

Add-In FluidMAT for Mathcad[®]

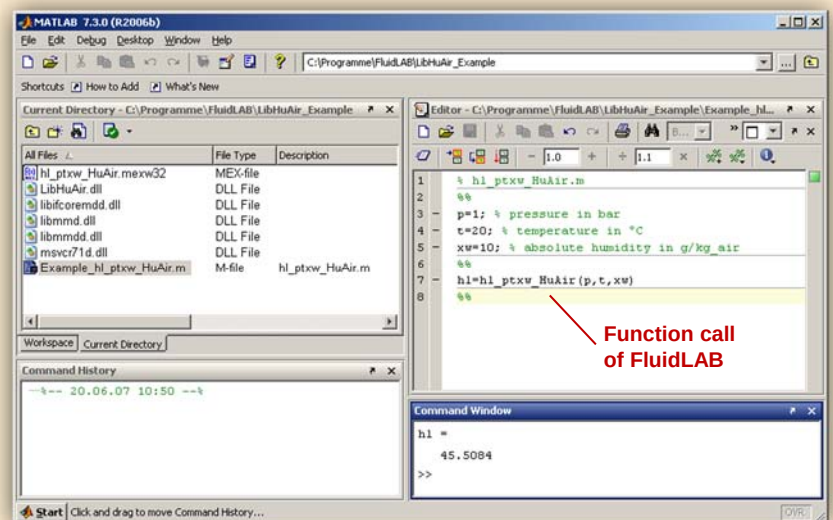
The property libraries can be used in Mathcad[®].



Function call of FluidMAT

Add-In FluidLAB for MATLAB[®]

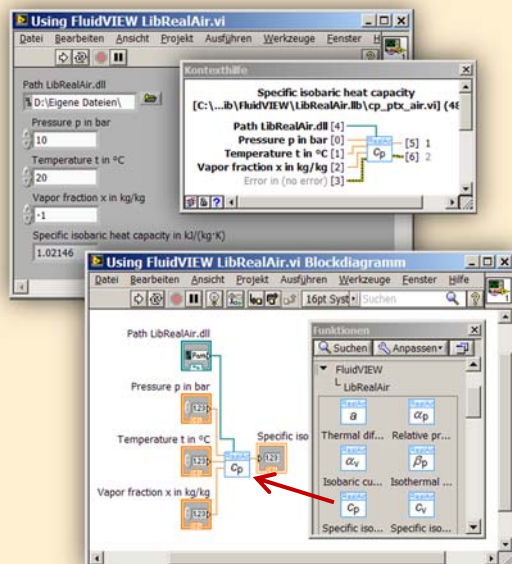
Using the Add-In FluidLAB the property functions can be called in MATLAB[®].



Function call of FluidLAB

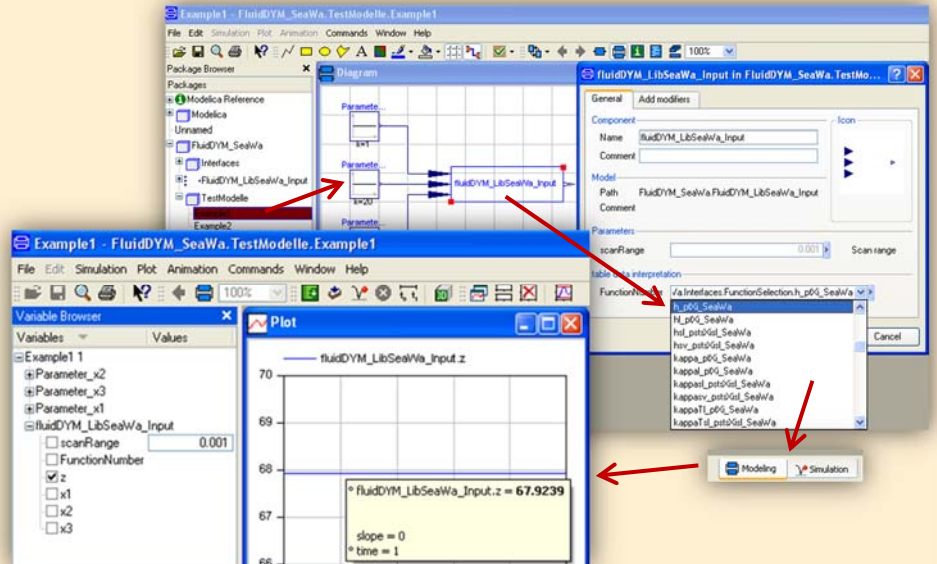
Add-On FluidVIEW for LabVIEW[®]

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

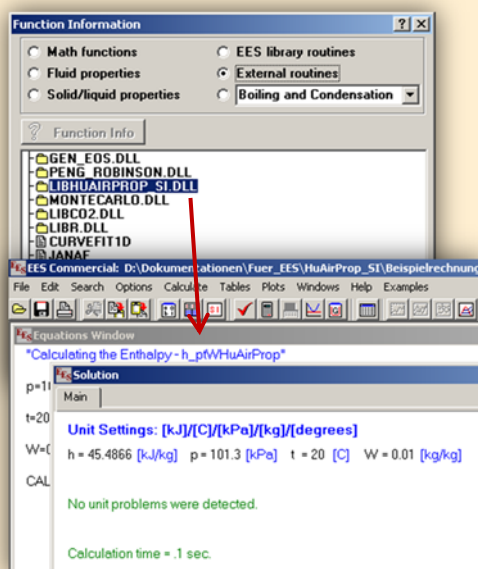


Add-In FluidDYM for DYMOLA[®] (Modelica) and SimulationX[®]

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



Add-In FluidEES for Engineering Equation Solver®



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



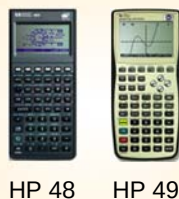
Online Property Calculator at www.thermodynamics-zittau.de

Property Software for Pocket Calculators

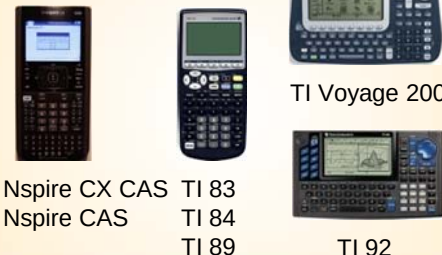
FluidCasio



FluidHP



FluidTI



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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

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6. Satisfied Customers

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