



Hochschule
Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

Faculty of
MECHANICAL ENGINEERING

Department of
TECHNICAL THERMODYNAMICS

Property Library for Carbon Dioxide

FluidEXL *Graphics*
with **LibCO2**
for Excel[®]

Prof. Hans-Joachim Kretzschmar

Dr. Ines Stoecker

Ines Jaehne

Matthias Kunick

S. Hasch

F. Elschner

Property Library for Carbon Dioxide

FluidEXL *Graphics*

LibCO2

Contents

- 0. Package Contents
 - 0.1 Zip-files for 32-bit Windows[®]
 - 0.2 Zip-files for 64-bit Windows[®]
- 1. Property Functions
- 2. Application of FluidEXL *Graphics* in Excel[®]
 - 2.1 Installing FluidEXL *Graphics*
 - 2.2 Registering FluidEXL *Graphics* as Add-In in Excel[®]
 - 2.3 The FluidEXL *Graphics* Help System
 - 2.4 Licensing the LibCO2 Property Library
 - 2.5 Example: Calculation of $h = f(p, t, x)$
 - 2.6 Removing FluidEXL *Graphics*
- 3. Program Documentation
 - 3.1 Ranges of Validity
 - 3.2 General Property Functions
 - 3.3 Property Functions for Solid Carbon Dioxide (Dry Ice)
- 4. Property Libraries for Calculating Heat Cycles, Boilers, Turbines, and Refrigerators
- 5. References
- 6. Satisfied Customers

© Zittau/Goerlitz University of Applied Sciences
Faculty of Mechanical Engineering
Department of Technical Thermodynamics
Professor Hans-Joachim Kretzschmar
Dr. Ines Stoecker
Phone: +49 3583-61-1846 or -1881
Fax: +49 3583-61-1846
E-mail: hj.kretzschmar@hszg.de
Internet: www.thermodynamics-zittau.de

0. Package Contents

0.1 Zip files for 32-bit Windows®

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

English zip file "CD_FluidEXL_Graphics_LibCO2_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>
LibCO2.dll	- Dynamic Link Library for use in Windows programs
LibCO2.hlp	- Help file for the LibCO2 property library
FluidEXL_Graphics_LibCO2_Docu_Eng.pdf	- User's Guide

German zip file "CD_FluidEXL_Graphics_LibCO2.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>
LibCO2.dll	- Dynamic Link Library for use in Windows programs
LibCO2.hlp	- Help file for the LibCO2 property library
FluidEXL_Graphics_LibCO2_Docu_Eng.pdf	- User's Guide

0.2 Zip files for 64-bit Windows®

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

English zip file "CD_FluidEXL_Graphics_LibCO2_x64_Eng.zip" including the following files and folders:

Files:

FluidEXL_Graphics_LibCO2_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
LibCO2.dll	- Dynamic link library for use in Windows® programs

LibCO2.hlp	- Help file for the LibCO2 property library
Setup.exe	- Self-extracting and self-installing program for FluidEXL ^{Graphics}

Folders:

vc redistrib_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_LibCO2_x64.zip" including the following files and folders:

Files:

FluidEXL_Graphics_LibCO2_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
LibCO2.dll	- Dynamic link library for use in Windows [®] programs
LibCO2.hlp	- Help file for the LibCO2 property library
Setup.exe	- Self-extracting and self-installing program for FluidEXL ^{Graphics}

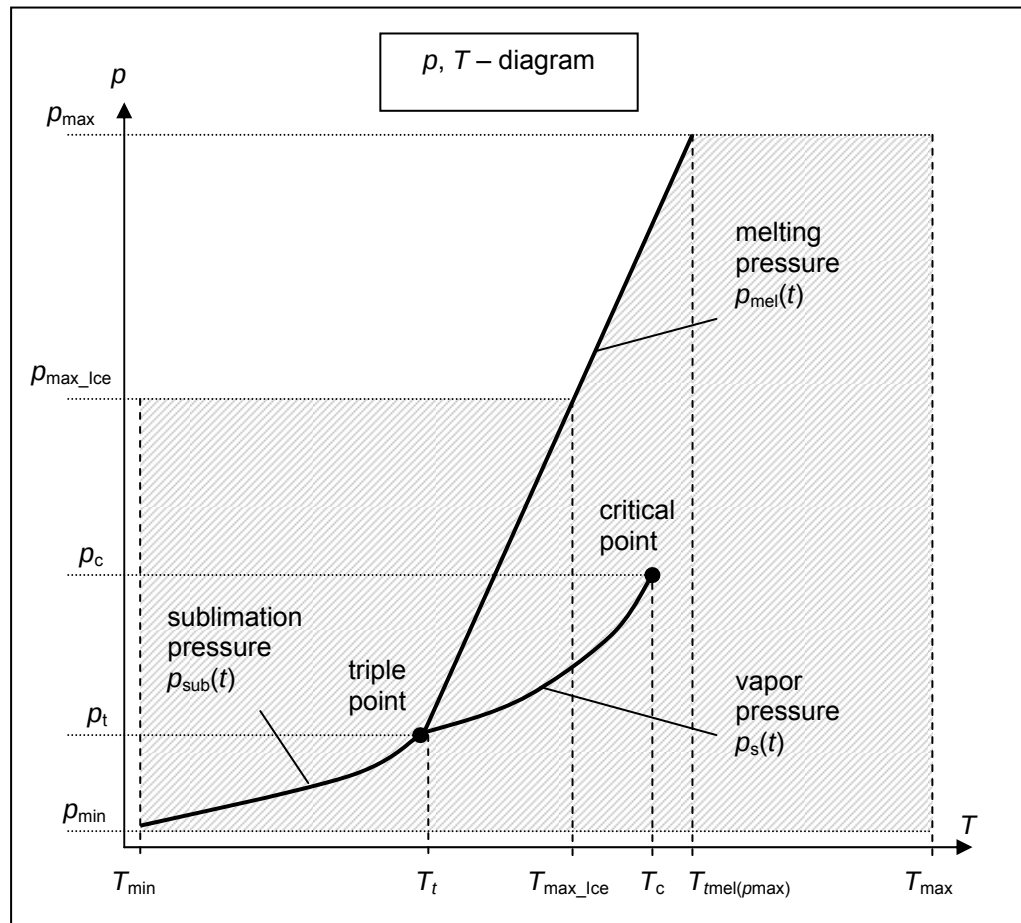
Folders:

vc redistrib_x64	- Folder containing the "Microsoft Visual C++ 2010 x64 Redistributable Pack"
WindowsInstaller3_1	- Folder containing the "Microsoft Windows Installer"

1. Property Functions

Units: t in °C
 p in bar
 x in kg /kg (Phase fraction, see the following explanations)

Range of Validity:



Reference State:

At $p = 1.01325$ bar and $T = 298.15$ K (25 °C) :
 $h = -0.938457860$ kJ/kg and $s = -0.00219606205$ kJ/(kg K)

Factor	Abbreviation	Value and Unit
Minimum temperature	$T_{\text{min}} (t_{\text{min}})$	85 K (−188.15 °C)
Maximum temperature	$T_{\text{max}} (t_{\text{max}})$	1500 K (1226.85 °C)
Triple temperature	$T_t (t_t)$	216.592 K (−56.558 °C)
Temperature at the critical point	$T_c (t_c)$	304.1282 K (30.9782 °C)
Maximum temperature of solid region	$T_{\text{max_Ice}} (t_{\text{max_Ice}})$	236.0309 K (−37.119 °C)
Maximum temperature of melting pressure curve	$T_{\text{mel}}(p_{\text{max}}) (t_{\text{mel}}(p_{\text{max}}))$	327.671 K (54.521 °C)
Minimum pressure	$p_{\text{min}} = p_{\text{sub}}(T_{\text{min}})$	$2.9081875815 \cdot 10^{-10}$ bar
Maximum pressure	p_{max}	8000 bar
Triple pressure	p_t	5.179618369088 bar
Pressure at the critical point	p_c	73.773 bar
Maximum pressure of solid region	$p_{\text{max_Ice}}$	1000 bar

General Property Functions

Functional Dependence	Function Name	Call from Fortran program	Call from the DLL LibCO2 as Parameter	Property or Function	Unit of the Result
$a = f(p, t, x)$	a_ptx_CO2	APTXXCO2(P,T,X)	C_APTXXCO2(A,P,T,X)	Thermal diffusivity	m ² /s
$c_p = f(p, t, x)$	cp_ptx_CO2	CPPTXXCO2(P,T,X)	C_CPPTXXCO2(CP,P,T,X)	Specific isobaric heat capacity	kJ/(kg K)
$\eta = f(p, t, x)$	eta_ptx_CO2	ETAPTXCO2(P,T,X)	C_ETAPTXCO2(ETA,P,T,X)	Dynamic viscosity	Pa s
$h = f(p, t, x)$	h_ptx_CO2	HPTXXCO2(P,T,X)	C_HPTXXCO2(H,P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p, t, x)$	kappa_ptx_CO2	KAPTXCO2(P,T,X)	C_KAPTXCO2(KAP,P,T,X)	Isentropic exponent	-
$\lambda = f(p, t, x)$	lambda_ptx_CO2	LAMPTXXCO2(P,T,X)	C_LAMPTXXCO2(LAM,P,T,X)	Thermal conductivity	W/(m K)
$\nu = f(p, t, x)$	ny_ptx_CO2	NYPTXXCO2(P,T,X)	C_NYPTXXCO2(NY,P,T,X)	Kinematic viscosity	m ² /s
$p_{\text{mel}} = f(t)$	pmel_t_CO2	PMELCO2(T)	C_PMELCO2(PMEL,T)	Melting pressure from temperature	bar
$p_{\text{sub}} = f(t)$	psub_t_CO2	PSUBCO2(T)	C_PSUBCO2(PSUB,T)	Sublimation pressure from temperature	bar
$p_s = f(t)$	ps_t_CO2	PSTCO2(T)	C_PSTCO2(PS,T)	Vapor pressure from temperature	bar
$Pr = f(p, t, x)$	Pr_ptx_CO2	PRPTXXCO2(P,T,X)	C_PRPTXXCO2(PR,P,T,X)	Prandtl-Number	-
$\rho = f(p, t, x)$	rho_ptx_CO2	ROPTXXCO2(P,T,X)	C_ROPTXXCO2(RHO,P,T,X)	Density	kg/ m ³
$s = f(p, t, x)$	s_ptx_CO2	SPTXXCO2(P,T,X)	C_SPTXXCO2(S,P,T,X)	Specific entropy	kJ/(kg K)
$t = f(p, h)$	t_ph_CO2	TPHCO2(P,H)	C_TPHCO2(T,P,H)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p, s)$	t_ps_CO2	TPSCO2(P,S)	C_TPSCO2(T,P,S)	Backward function: Temperature from pressure and entropy	°C

Functional Dependence	Function Name	Call from Fortran program	Call from the DLL LibCO2 as Parameter	Property or Function	Unit of the Result
$t_{\text{mel}} = f(p)$	tmel_p_CO2	TMELCO2(P)	C_TMELCO2(TMEL,P)	Melting temperature from pressure	°C
$t_{\text{sub}} = f(p)$	tsub_p_CO2	TSUBCO2(P)	C_TSUBCO2(TSUB,P)	Sublimation temperature from pressure	°C
$t_s = f(p)$	ts_p_CO2	TSPCO2(P)	C_TSPCO2(TS,P)	Saturation temperature from pressure	°C
$v = f(p,t,x)$	v_ptx_CO2	VPTXCO2(P,T,X)	C_VPTXCO2(V,P,T,X)	Specific volume	m³/kg
$w = f(p,t,x)$	w_ptx_CO2	WPTXCO2(P,T,X)	C_WPTXCO2(W,P,T,X)	Isentropic speed of sound	m/s
$x = f(p,h)$	x_ph_CO2	XPHCO2(P,H)	C_XPHCO2(X,P,H)	Backward function: Phase fraction from pressure and enthalpy	kg/kg
$x = f(p,s)$	x_ps_CO2	XPSCO2(P,S)	C_XPSCO2(X,P,S)	Backward function: Phase fraction from pressure and entropy	kg/kg

Property Functions for Solid Carbon Dioxide (Dry Ice)

Functional Dependence	Function Name	Call from Fortran program	Call from the DLL LibCO2 as Parameter	Property or Function	Unit of the Result
$a = f(p,t)$	aICE_pt_CO2	APICETCO2(P,T)	C_APICEPTCO2 (A, P, T)	Thermal diffusivity	m²/s
$c_p = f(p,t)$	cpICE_pt_CO2	CPICETCO2(P,T)	C_CPICEPTCO2 (CP, P, T)	Specific isobaric heat capacity	kJ/(kg K)
$h = f(p,t)$	hICE_pt_CO2	HICETCO2(P,T)	C_HICEPTCO2 (H, P, T)	Specific enthalpy	kJ/ kg
$\lambda = f(t)$	lambdaICE_t_CO2	LAMICETCO2(T)	C_LAMICETCO2 (LAM,T)	Thermal conductivity	W/(m K)
$\rho = f(p,t)$	rhoICE_pt_CO2	RHOICETCO2(P,T)	C_RHOICEPTCO2 (RHO, P, T)	Density	kg/ m³
$s = f(p,t)$	sICE_pt_CO2	SICETCO2(P,T)	C_SICEPTCO2 (S, P, T)	Specific entropy	kJ/ (kg K)

Functional Dependence	Function Name	Call from Fortran program	Call from the DLL LibCO2 as Parameter	Property or Function	Unit of the Result
$v = f(p, t)$	vICE_pt_CO2	VICETCO2(P, T)	C_VICEPTCO2 (V, P, T)	Specific volume	m ³ /kg
$t = f(p, h)$	tlCE_ph_CO2	TICEHCO2(P, H)	C_TICEPHCO2 (T, P, H)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p, s)$	tlCE_ps_CO2	TICESCO2(P, S)	C_TICEPSCO2 (T, P, S)	Backward function: Temperature from pressure and entropy	°C

Details on the Phase Fraction x

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

The two phase regions wet vapor region, melting region and sublimation region (cp. the following $\lg p, h$ -diagram) are calculated automatically by the subprograms. Please consider the following facts:

1. Wet Vapor Region ($0 \leq x \leq 1$):

The phase fraction x equates to the vapor fraction x in the wet vapor region in (kg dry saturated vapor)/(kg wet vapor).

In this case 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. If values for both p and t are entered when calculating wet vapor, the program will consider p and t to be appropriate to represent the vapour pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000 .

When calculating wet vapor, x results in a value between 0 and 1 ($x = 0$ for boiling liquid, $x = 1$ for dry saturated vapor). In this case, the backward functions result in the appropriate value between 0 and 1 for x .

Wet vapor region: Temperature range from $T_t = 216.592 \text{ K}$ ($t_t = -56.558 \text{ °C}$) to $T_c = 304.1282 \text{ K}$ ($t_t = 30.9782 \text{ °C}$)

Pressure ranges from $p_t = 5.179618369088 \text{ bar}$ to $p_c = 73.773 \text{ bar}$

2. Melting Region ($10 \leq x \leq 11$):

The phase fraction x equates to the liquid fraction x in the melting region in (kg solidifying liquid)/(kg melt), whereas melt is a mixture of melting solid and solidifying liquid.

In this case 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 10 and 11. If values for both p and t are entered, the program will consider p and t to be appropriate to represent the melting pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000 .

When calculating a melt, x results in a value between 10 and 11 ($x = 10$ for melting solid, $x = 11$ for solidifying liquid). In this case, the backward functions result in the appropriate value between 10 and 11 for x .

Melting region: Temperature range from $T_{\max_Ice} = 236.0309 \text{ K}$ ($t_{\max_Ice} = -37.119 \text{ °C}$) to $T_t = 216.592 \text{ K}$ ($t_t = -56.558 \text{ °C}$)
 Pressure range from $p_t = 5.179618369088 \text{ bar}$ to $p_{\max_Ice} = 1000 \text{ bar}$

Only the limiting curve on the right hand side, thus solidifying liquid ($x = 11$) is calculated for pressures p for which applies $p_{\max_Ice} < p \leq p_{\max}$.

3. Sublimation Region ($100 \leq x \leq 101$):

The phase fraction x equates to the vapor fraction x in the sublimation region in (kg desublimating vapor)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating solid and desublimating vapor.

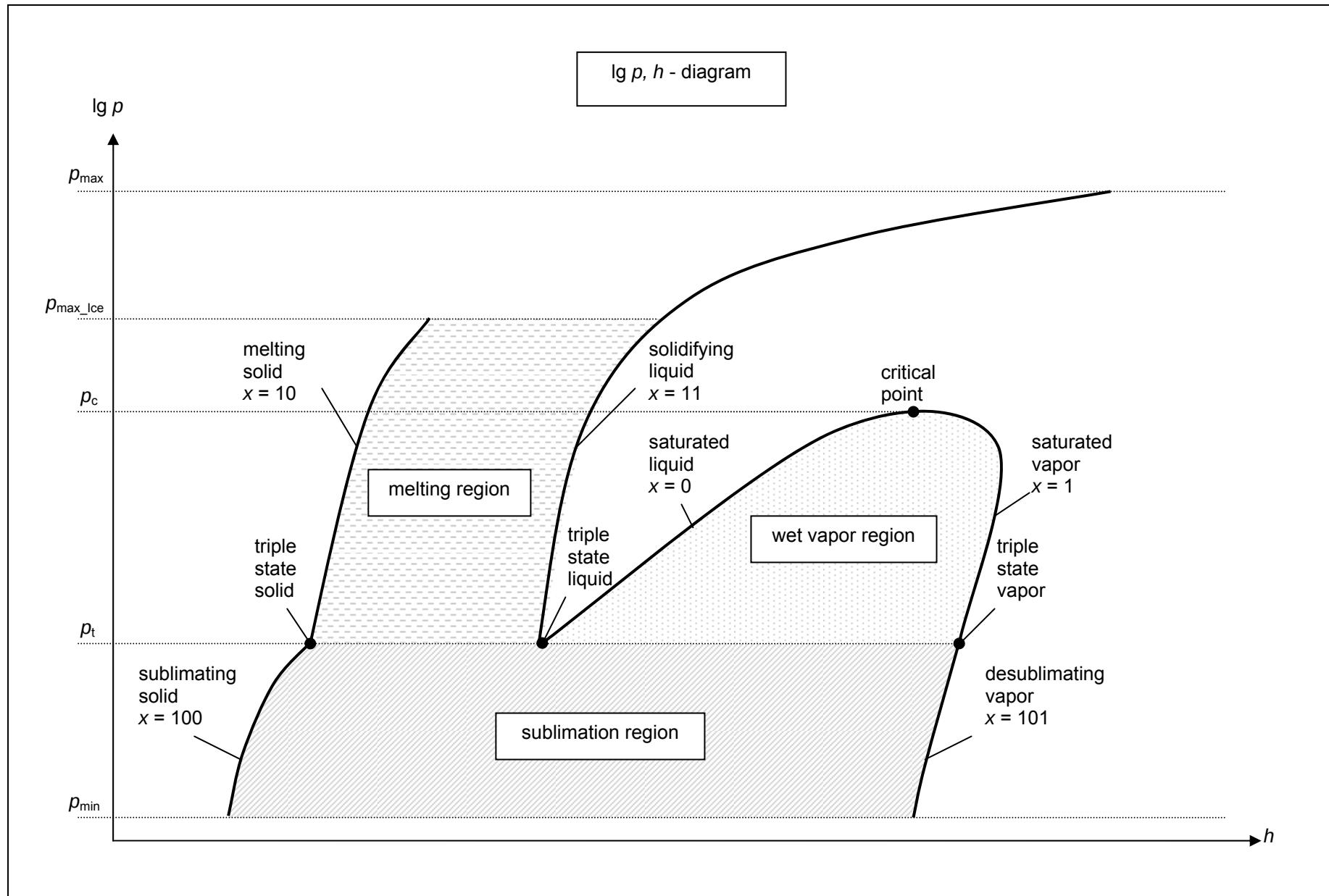
In this case it is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 100 and 101. If values for both p and t are entered, the program will consider p and t to be appropriate to represent the sublimation pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000 .

When calculating sublimation powder, x takes a value between 100 and 101 ($x = 100$ for sublimating solid, $x = 101$ for desublimating vapor). In this case, the backward functions result in the appropriate value between 100 and 101 for x .

Sublimation region: Temperature range from $T_{\min} = 85 \text{ K}$ ($t_{\min} = -188.15 \text{ °C}$) to $T_t = 216.592 \text{ K}$ ($t_t = -56.558 \text{ °C}$)
 Pressure range from $p_{\min} = 2.9081875815 \cdot 10^{-10} \text{ bar}$ to $p_t = 5.179618369088 \text{ bar}$

Note:

If the input values are located outside the range of validity, the calculated function will always result in -1000 . Please find more exact details on every function and its corresponding range of validity in the enclosed software documentation in 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 carbon dioxide from the LibCO2 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 LibCO2 library. In this case, follow the subsection "Adding the LibCO2 Library" on page 2/11.

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

In this section, the installation of FluidEXL^{Graphics} for a 32-bit Windows[®] 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_LibCO2_Eng.zip" (for English version of Windows)

"CD_FluidEXL_Graphics_LibCO2.zip" (for German version of Windows)

you will see the folder

CD_FluidEXL_Graphics_LibCO2_Eng (for English version of Windows)

CD_FluidEXL_Graphics_LibCO2 (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_LibCO2_Docu_Eng.pdf

LibCO2.dll

LibCO2.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)
LibCO2.dll	
LibCO2.hlp	

from the extracted folder

CD_FluidEXL_Graphics_LibCO2_Eng	(for English version of Windows)
CD_FluidEXL_Graphics_LibCO2	(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 Windows[®]

In this section, the installation of FluidEXL^{Graphics} for a 64-bit Windows[®] 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_LibCO2_x64_Eng.zip"	(for English version of Windows)
"CD_FluidEXL_Graphics_LibCO2_x64.zip,"	(for German version of Windows)

you will see the folder

"CD_FluidEXL_Graphics_LibCO2_Eng"	(for English version of Windows)
"CD_FluidEXL_Graphics_LibCO2"	(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_LibCO2_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)
LibCO2.dll	
LibCO2.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).

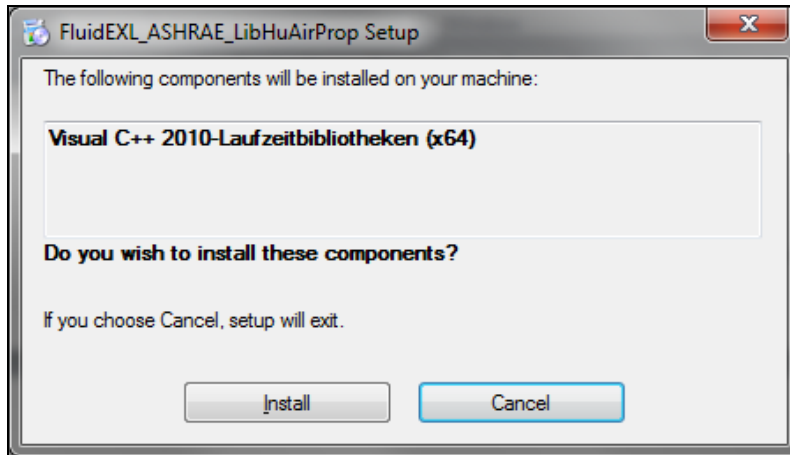


Figure 2.2: Installing the "Visual C++ 2010 runtime library (x64)"

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).

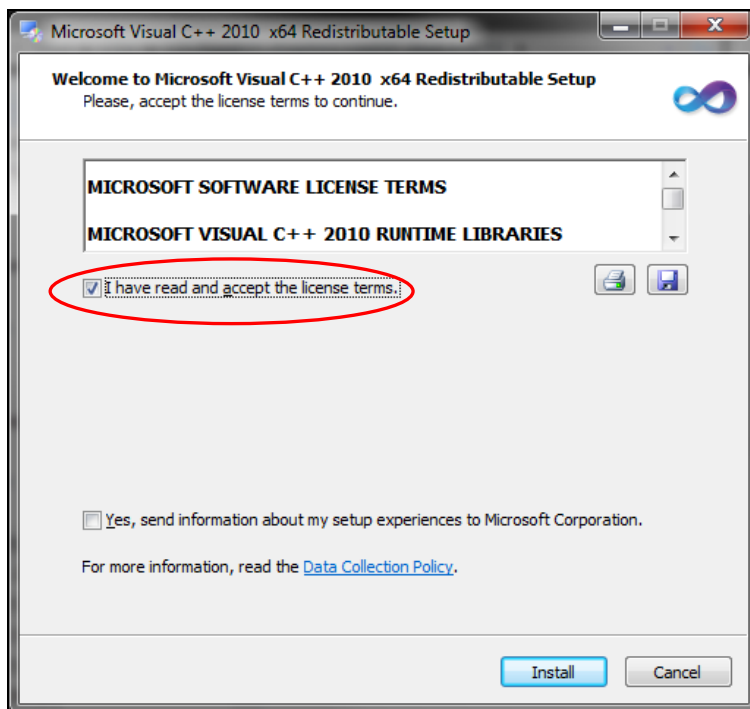


Figure 2.3: Accepting the license terms

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).

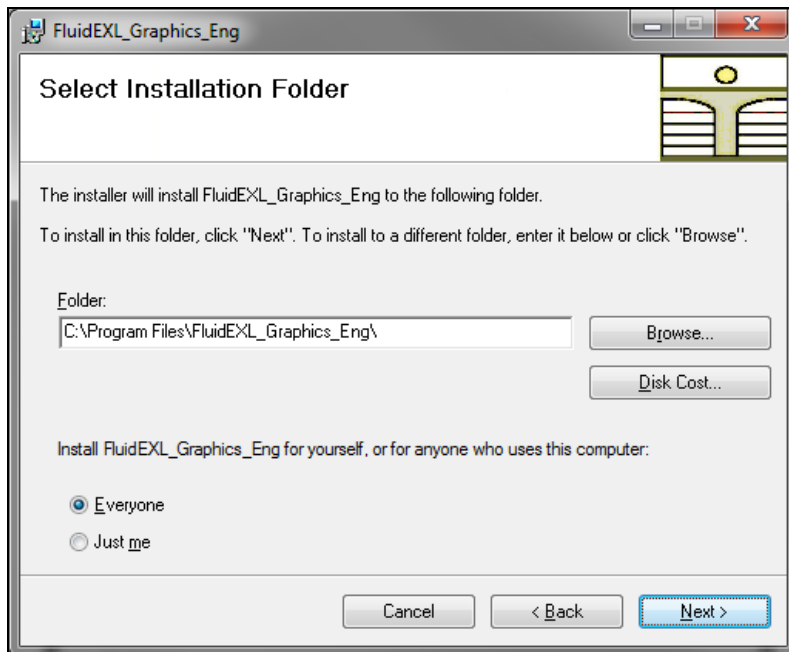


Figure 2.4: Choosing the installation folder

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)

LibCO2.dll
LibCO2.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.

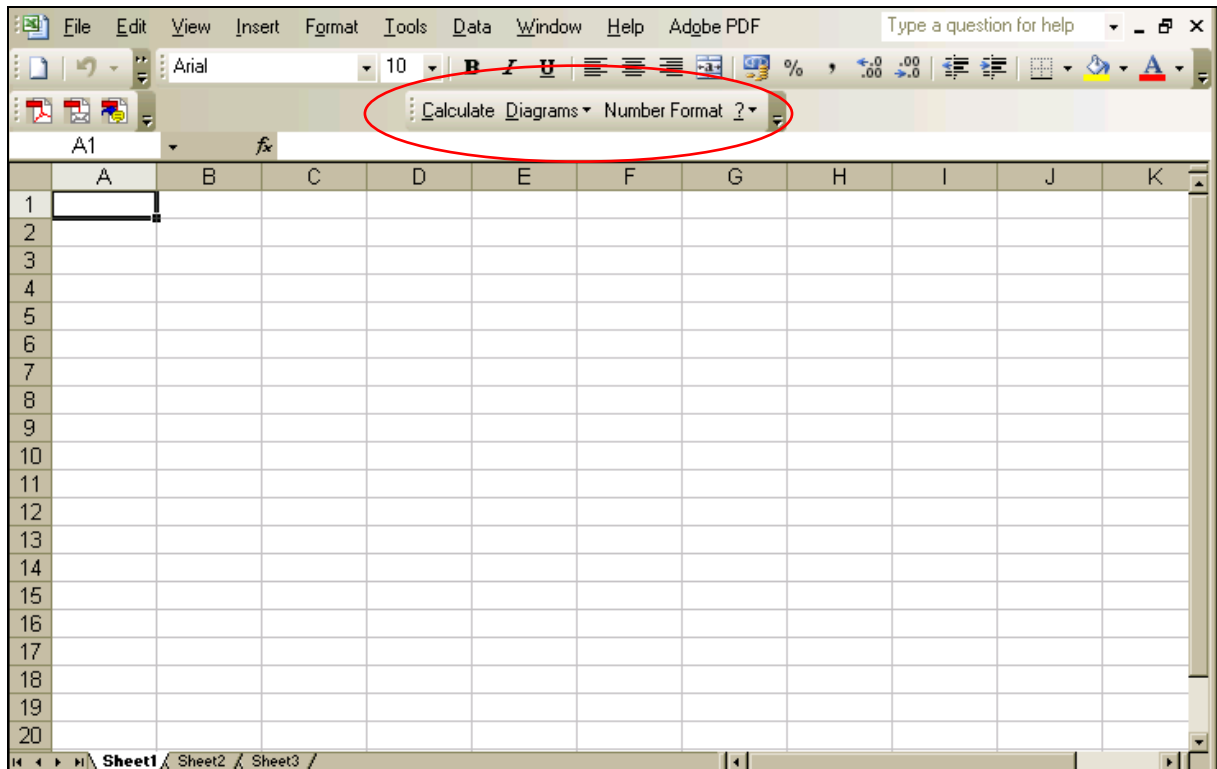


Figure 2.5: Menu bar of FluidEXL*Graphics*

From within Excel you can now select the "Carbon Dioxide LibCO2" 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)

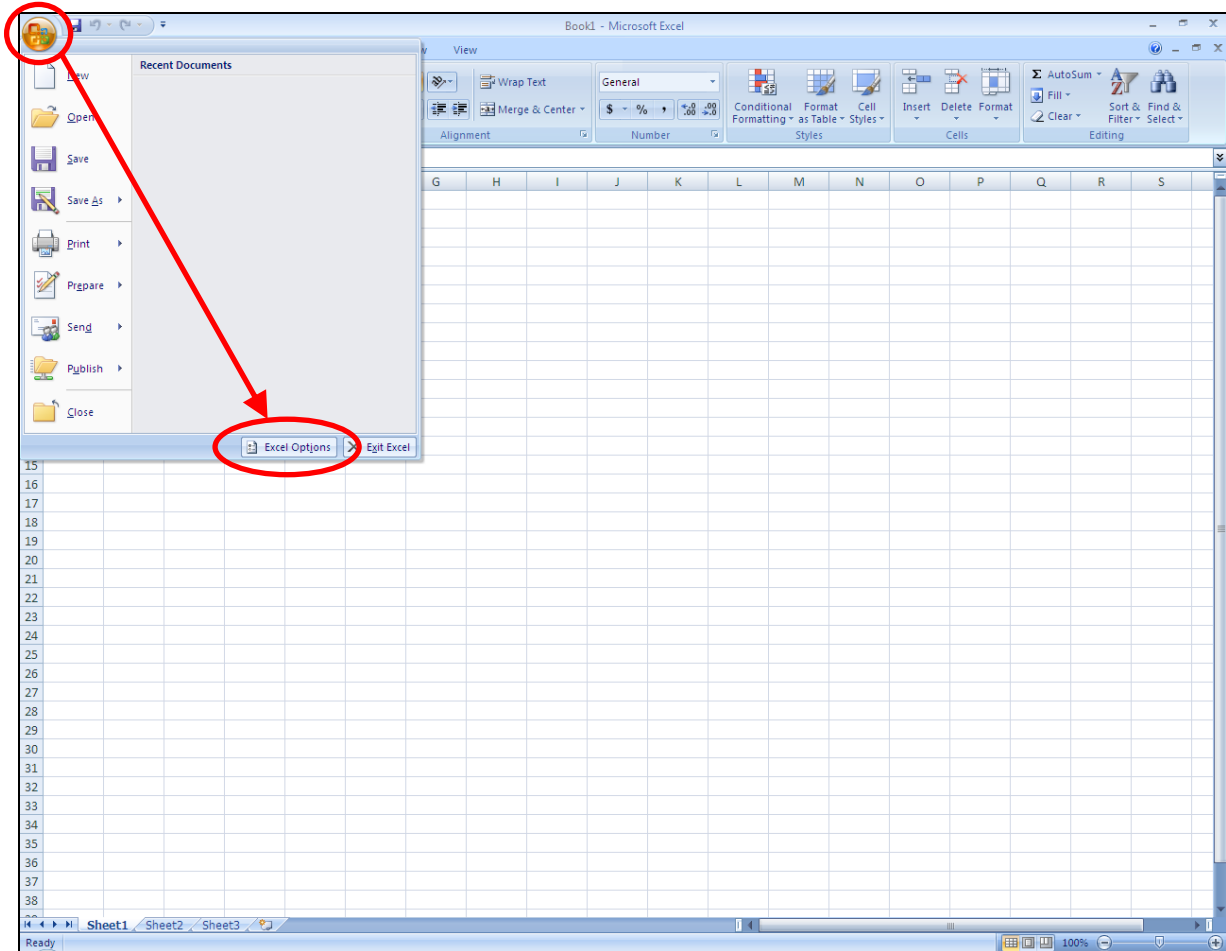


Figure 2.6: Registering FluidEXL *Graphics* as Add-In in Excel® 2007

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

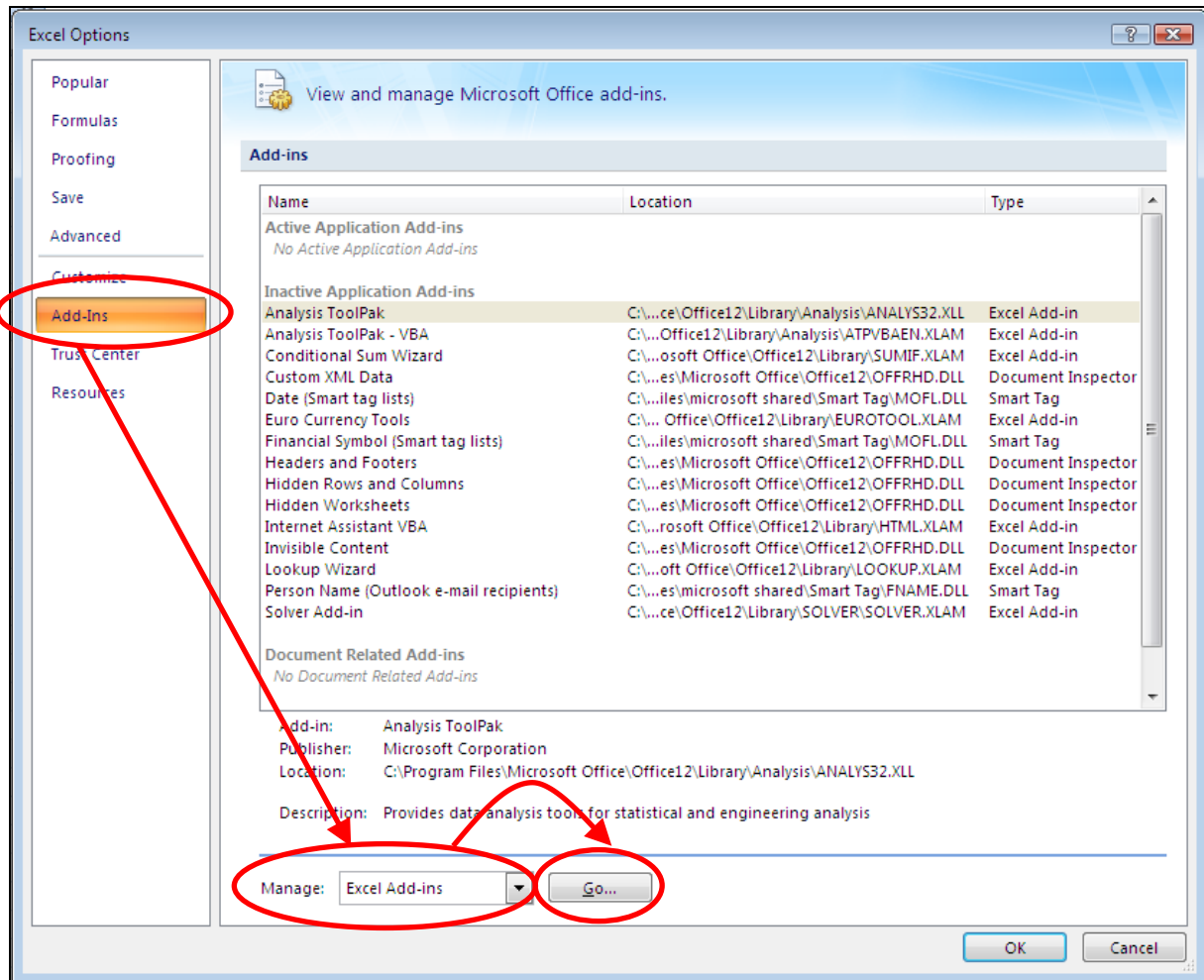


Figure 2.7: Dialog window "Add-Ins"

- 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."

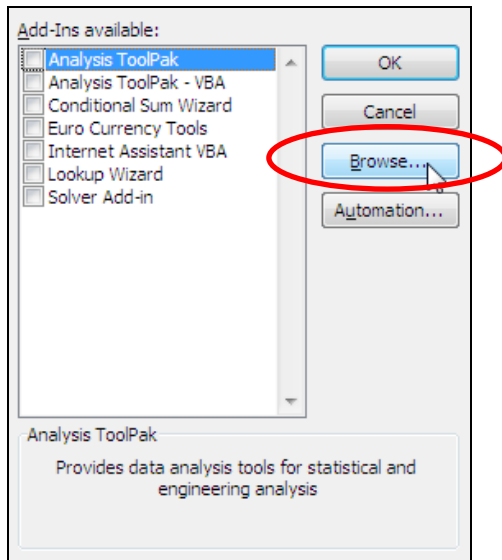


Figure 2.8: Dialog window "Add-Ins available"

- 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.)

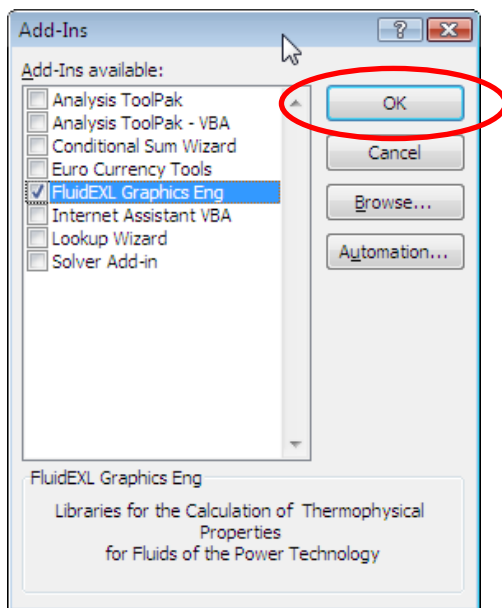


Figure 2.9: Dialog window "Add-Ins"

- 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.

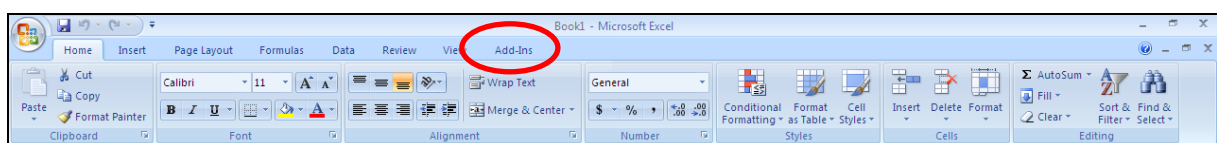


Figure 2.10: Menu item "Add-Ins"

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

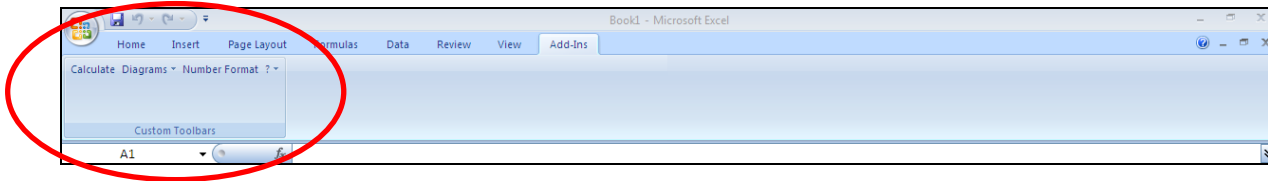


Figure 2.11: FluidEXL^{Graphics} menu bar

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 LibCO2 Library (FluidEXL^{Graphics} is already installed)

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

FluidEXL_Graphics_Eng.xla	(for English version of Windows)
FluidEXL_Graphics.xla	(for German version of Windows)
LibCO2.dll	
LibCO2.hlp	

provided in the extracted folder

CD_FluidEXL_Graphics_LibCO2_Eng	(for English version of Windows)
CD_FluidEXL_Graphics_LibCO2	(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.

From within Excel you can now select the "Carbon Dioxide LibCO2" DLL library property functions via this menu bar (cf. part 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 "Carbon Dioxide LibCO2" library under "Or select a category:" in the "Insert Function" window which will appear.
- Click the "Help on this function" link 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 "LibCO2.hlp" cannot be found, you will be asked whether you want to look for it yourself – answer with "Yes." Click on the "LibCO2.hlp" file in the installation menu of FluidEXLGraphics in the window which is opened, the standard being

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

and click "OK" 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).

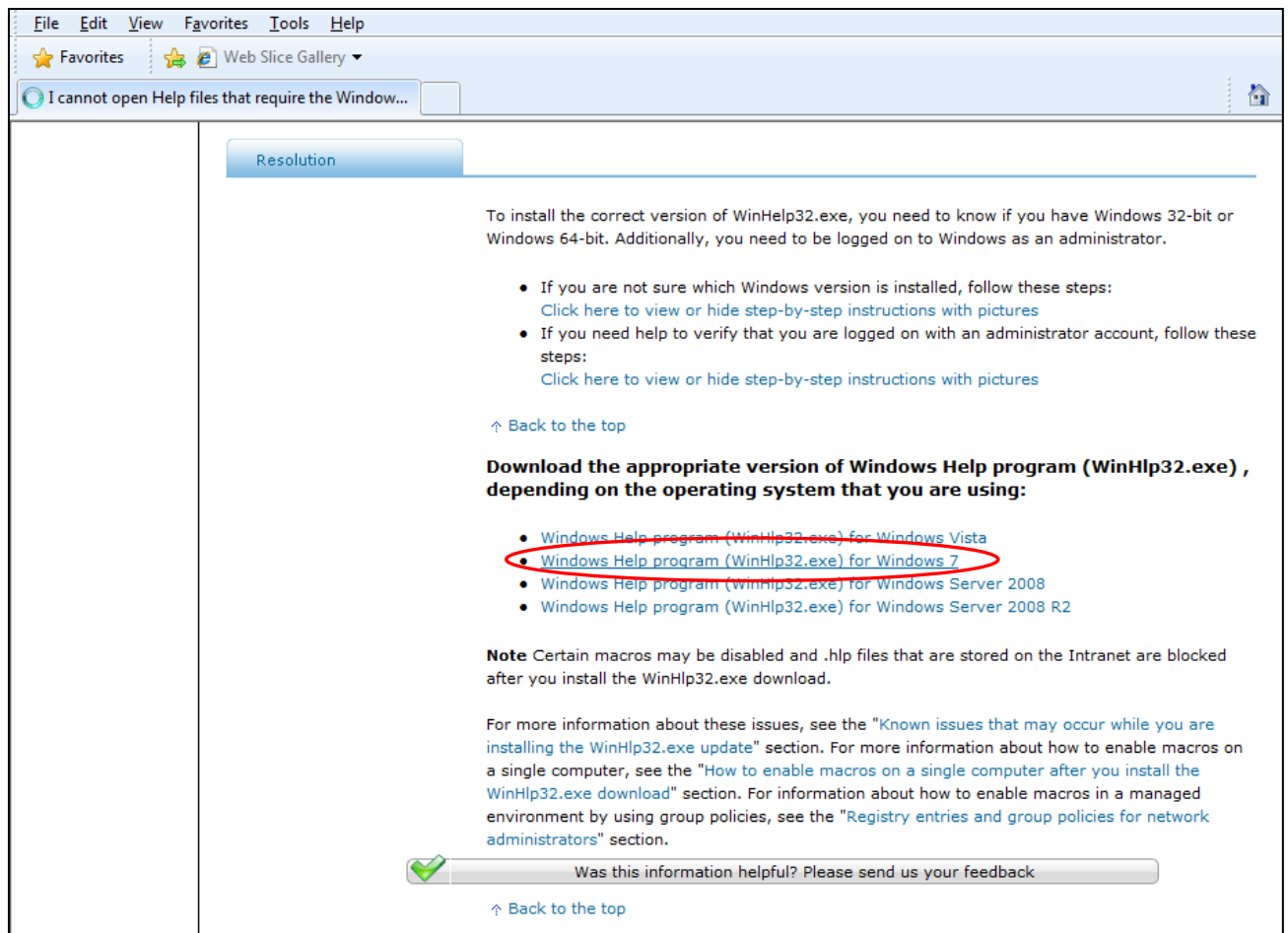


Figure 2.13: Selecting your Windows version

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).

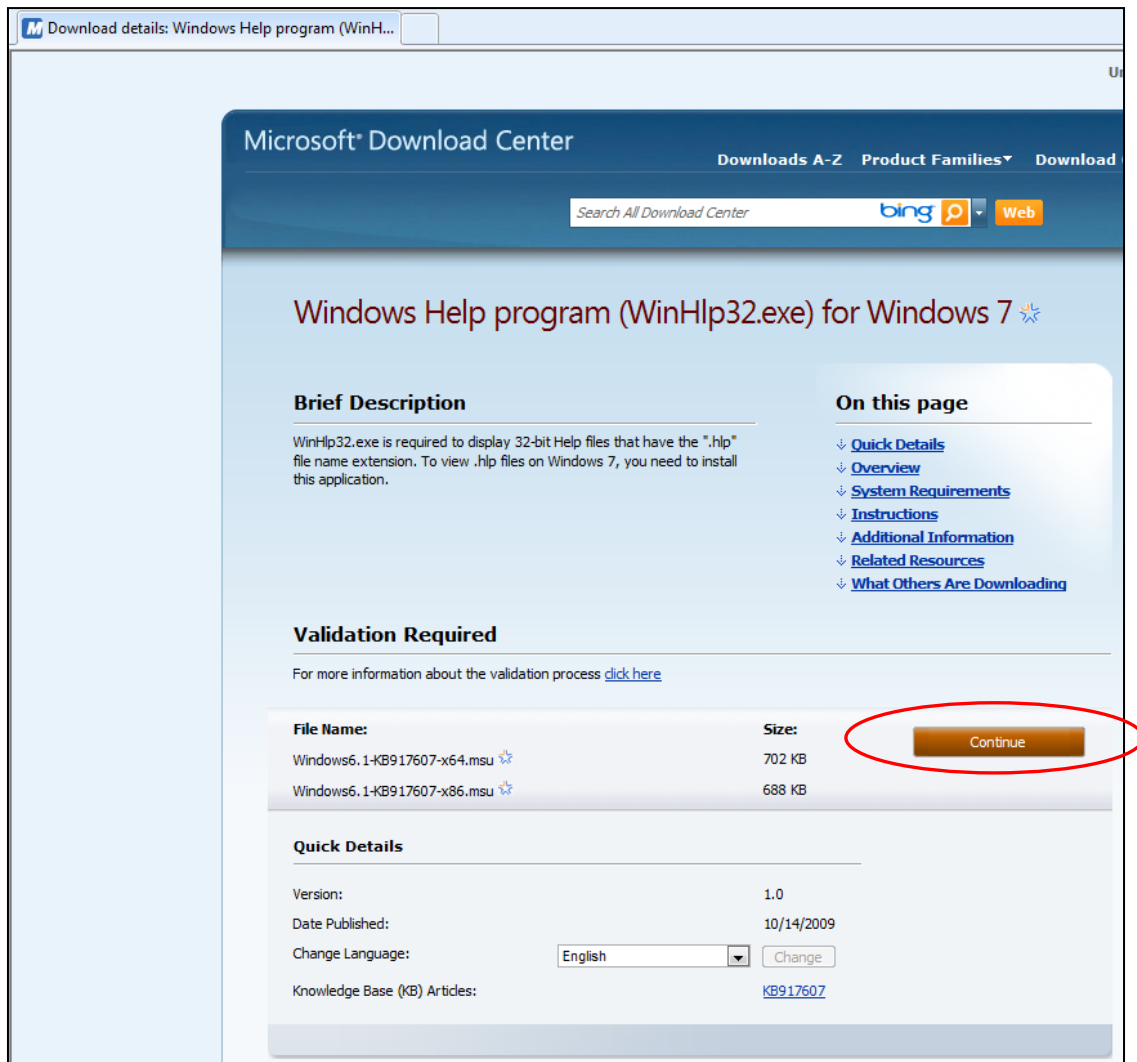


Figure 2.14: Microsoft® Download Center

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).

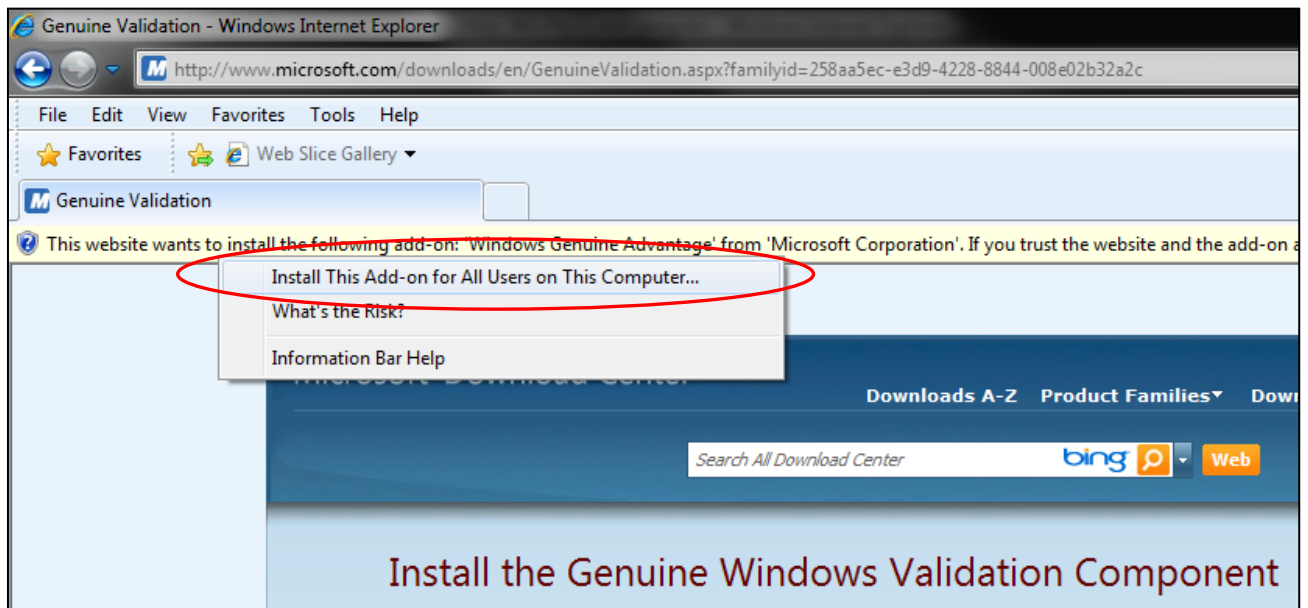


Figure 2.15: Installing the Genuine Windows Validation Component

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).

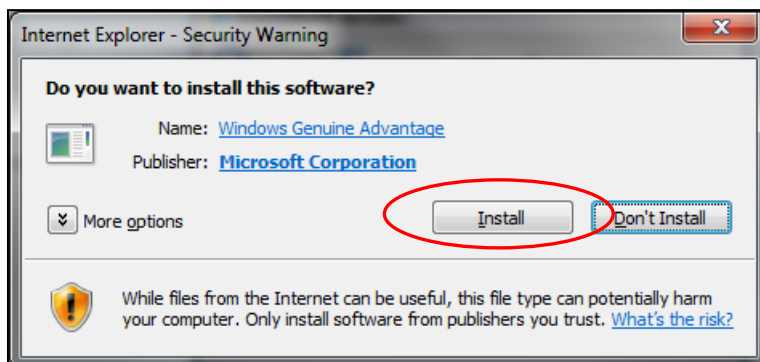


Figure 2.16: Internet Explorer – Security Warning

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

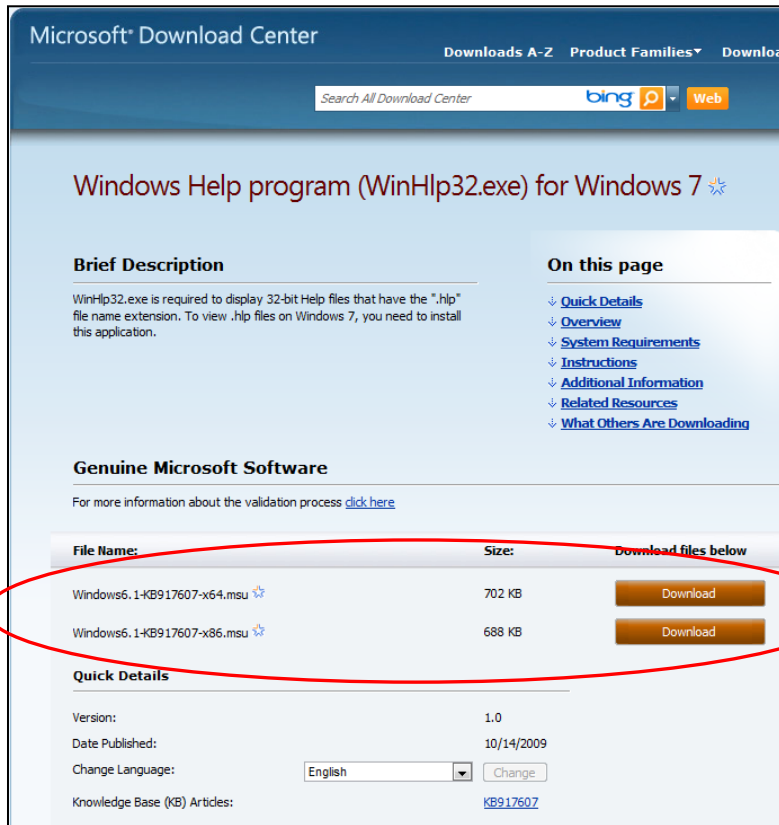


Figure 2.17: Downloading the Windows Help program

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.

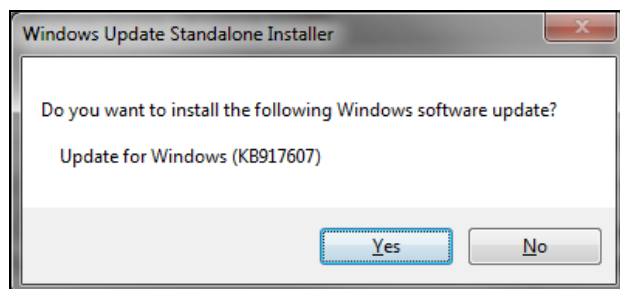


Figure 2.18: Windows Update Standalone Installer

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)

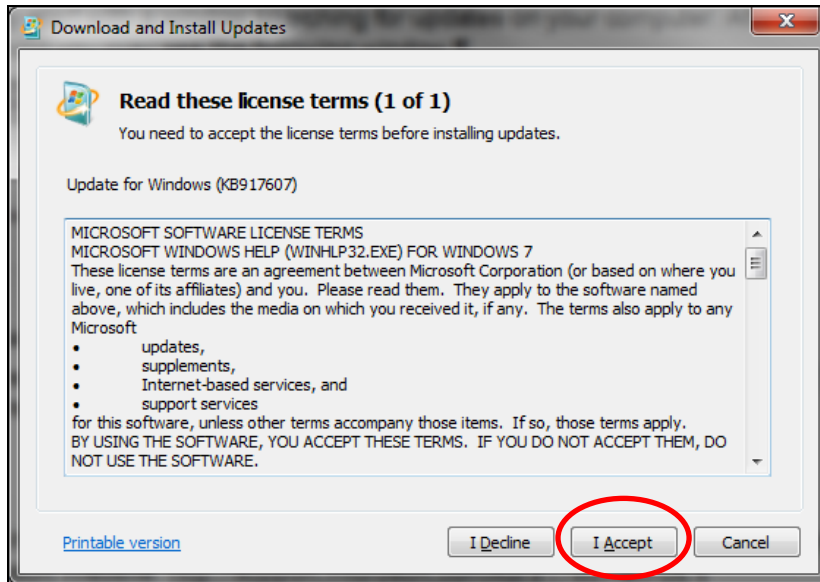


Figure 2.19: Windows License Terms

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

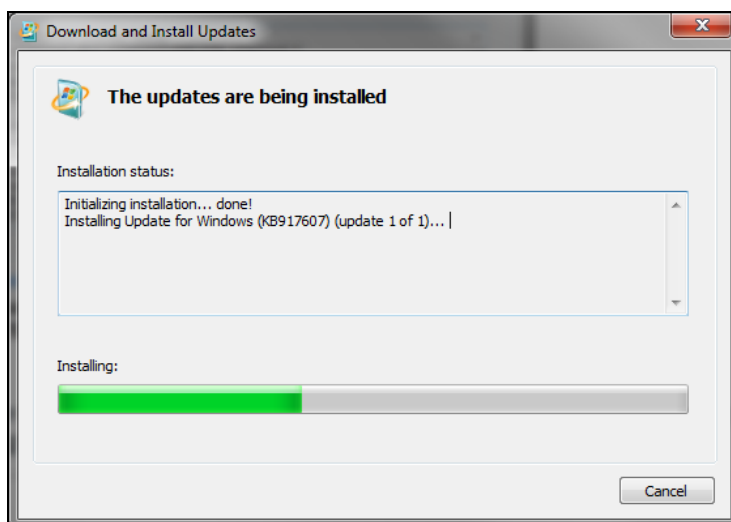


Figure 2.20: Installation process

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 LibCO2 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).

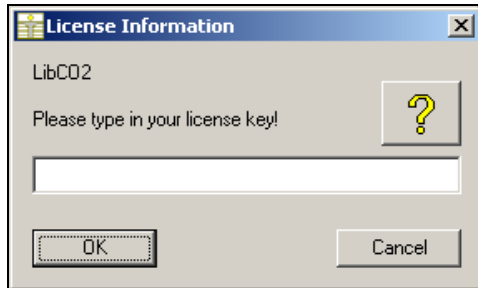


Figure 2.21: "License Information" window

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:

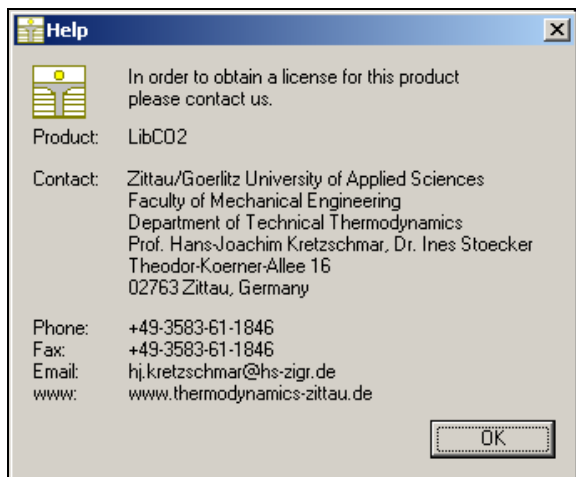


Figure 2.22: "Help" window

If you do not enter a valid license it is still possible to start Excel by clicking "Cancel" twice. In this case, the LibCO2 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 LibCO2 property library, you have to delete the files

LibCO2.dll
LibCO2.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 $h = f(p, t, x)$

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*. Please carry out the following steps:

- Start Excel[®]
- Enter a value for p in bar into a cell
(Range of validity: $p = 2.9081875815 \cdot 10^{-10}$ bar ... 8000 bar)
⇒ e.g.: Enter 10 into cell A2.

- Enter a value for t in °C into a cell
(Range of validity: $t = t_{\text{mel}}$... 826.85 °C)
⇒ e.g.: Enter 25 into cell B2.

- Enter a 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.

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

Wet-steam region

When calculating wet steam, a value between 0 and 1 ($x = 0$ for boiling liquid, $x = 1$ for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for x . 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 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 property of the chosen function to be calculated results in -1000 .

(CO₂ saturation line: $t_t = -56.558$ °C ... $t_c = 30.9782$ °C
 $p_t = 5.179618369088$ bar ... $p_c = 73.773$ bar)

⇒ e.g. Enter -1 into cell C2.

- Click the cell in which the enthalpy h calculated in kJ/kg is to be displayed.
⇒ e.g. Click the cell D2.
- Click "Calculate" in the FluidEXL *Graphics* menu bar.
Now, the "Insert Function" window appears (see Figure 2.23).

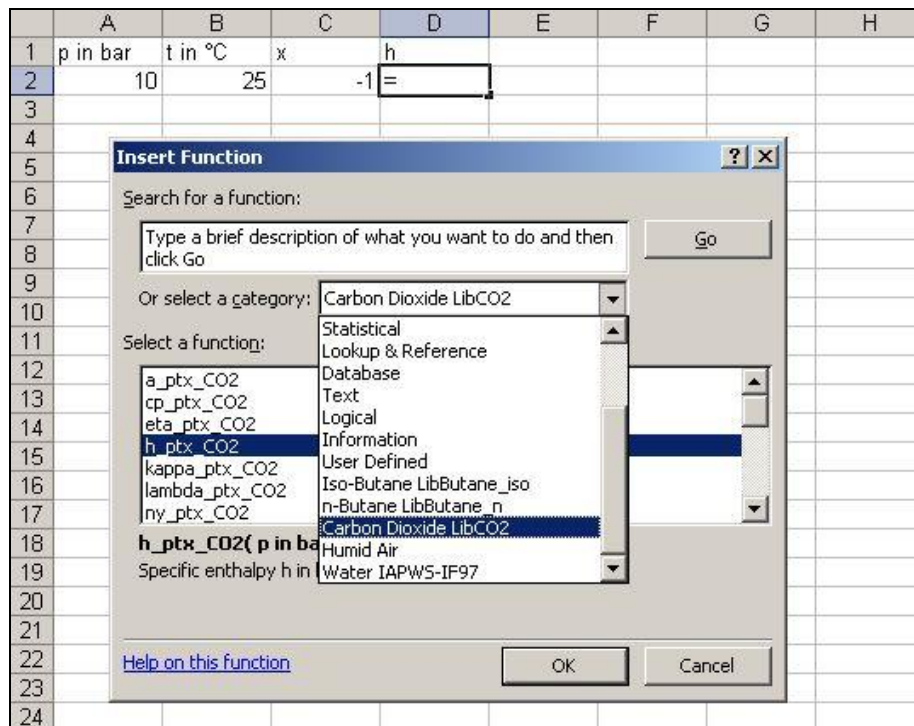


Figure 2.23: Selecting library and function

- Search and click the "Carbon Dioxide LibCO2" library in the upper list box next to "Or select a category:".
- Search and click the "h_ptx_CO2" function in the lower list box under "Select a function:". Here it is possible to get more information on range of validity, measuring units, error responses, etc. by clicking the "Help on this function" button.
- Click "OK".
The window shown in Figure 2.24 appears.

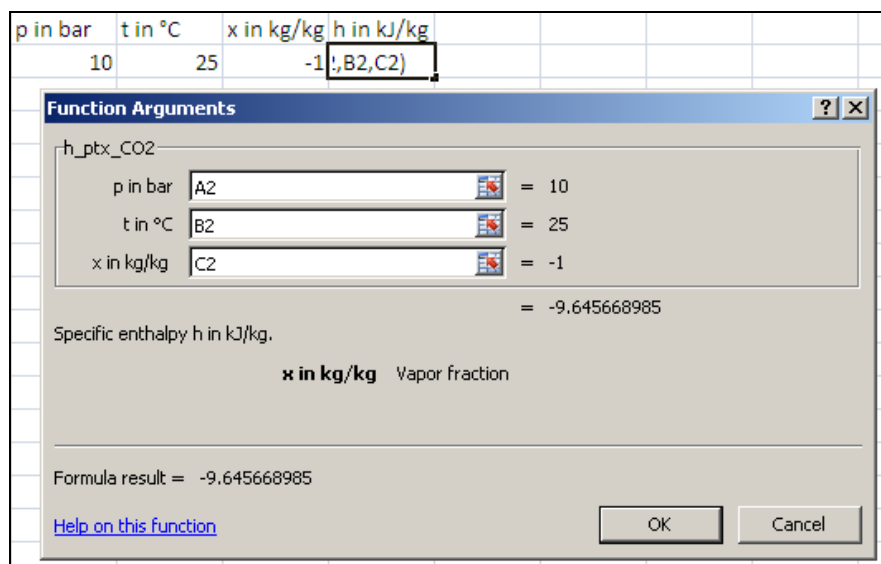


Figure 2.24: Entering the given values for the property calculation

- The cursor is situated on the line 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.
- Click the "OK" button.

The result for h in kJ/kg appears in the cell selected above.

⇒ The result in our sample calculation here is: $h = -9.645668985$ kJ/kg.

The calculation of $h = f(p, t, x)$ has thus been carried out. You can now arbitrarily change the values for p , t , or x in the appropriate cells. The 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.

Note.

If the calculation results in -1000 , this indicates that the values entered are located outside the range of validity of LibCO2. More detailed information on each function and its range of validity is available in Chapter 3.

For further property functions calculable in FluidEXL^{Graphics}, please see the function table in Chapter 1.

Number Formats

When using FluidEXL *Graphics* you have the option of choosing special number formats in advance.

Changes can be made as follows:

- Click the cell or select and click on the cells you wish to format.
(In empty cells the new format will be applied once a value has been entered.)
- Click "Number Format" in the FluidEXL *Graphics* menu bar.
- Select the desired number format in the dialog box which appears:
 - "STD – Standard": Insignificant zeros behind the decimal point are not shown.
 - "FIX – Fixed Number of Digits": All set decimal places are shown, including insignificant zeros.
 - "SCI – Scientific Format": Numbers are always shown in the exponential form with the set number of decimal places.
- Set the "Number of decimal places" by entering the number into the appropriate window.
- Confirm this by clicking the "OK" button.

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

STD	1.23
FIX	1.230
SCI	1.230E+00

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

2.6 Removing FluidEXL *Graphics*

Should you wish to remove only the LibCO2 library, delete the files

LibCO2.dll

LibCO2.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.

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

LibCO2.dll

LibCO2.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.

Now FluidEXL *Graphics* has been removed.

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

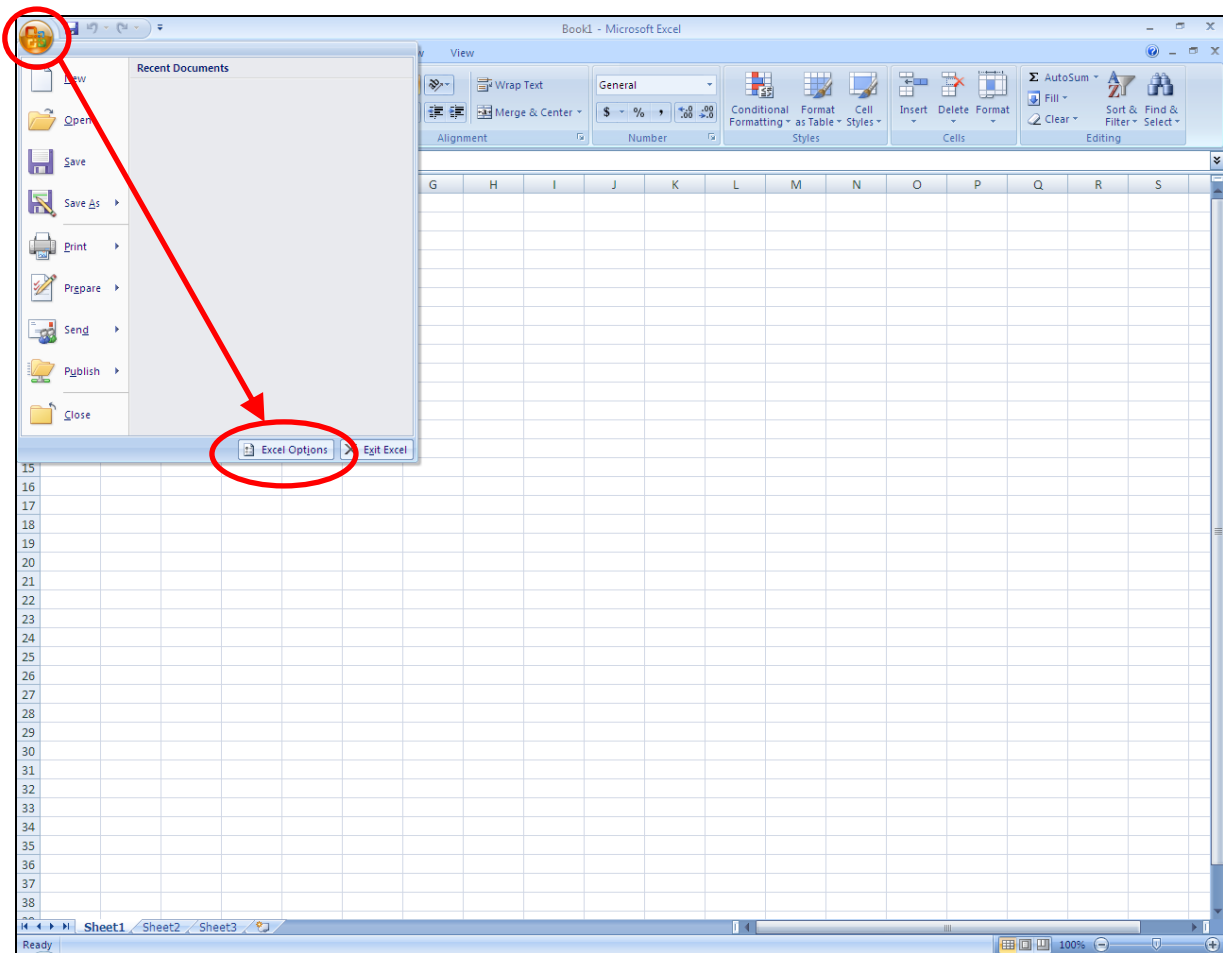


Figure 2.28: Unregistering FluidEXL *Graphics* as Add-In in Excel® 2007

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

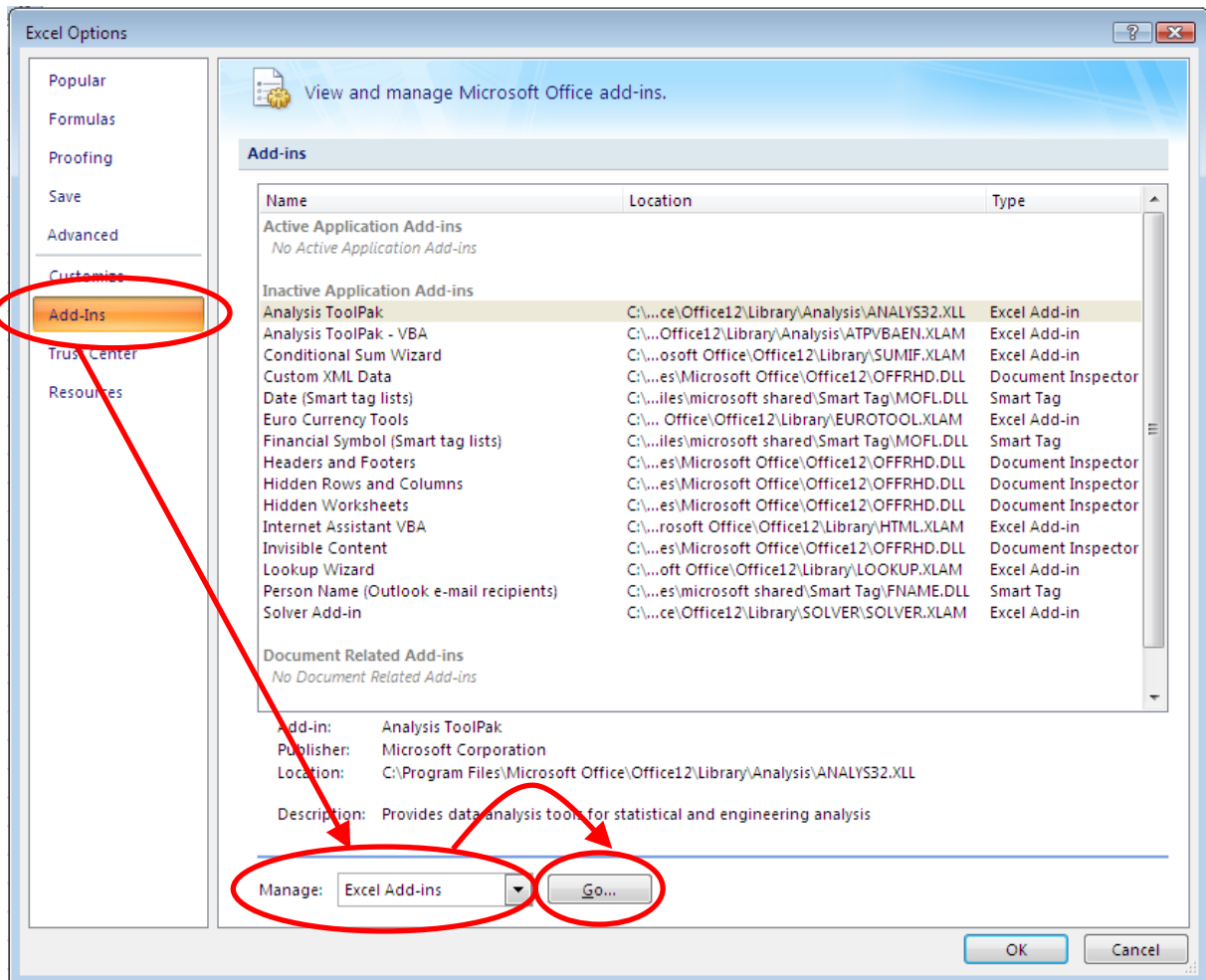


Figure 2.29: Dialog window "Add-Ins"

- 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.

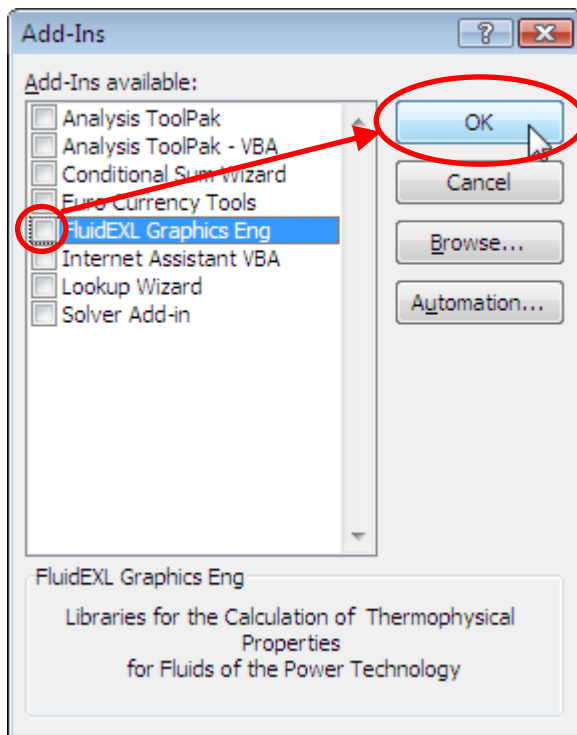


Figure 2.30: Dialog window "Add-Ins"

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.

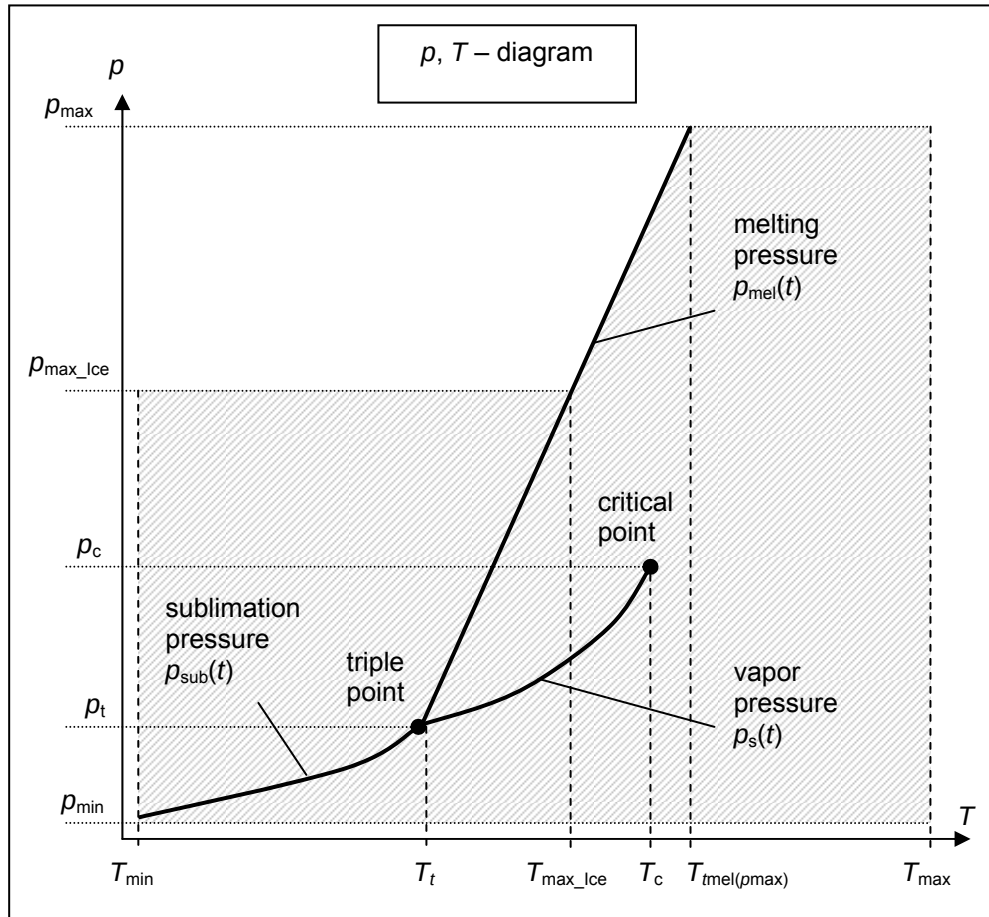
Answer the question of whether all shared components should be removed with "Yes to All."

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

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

3. Program Documentation

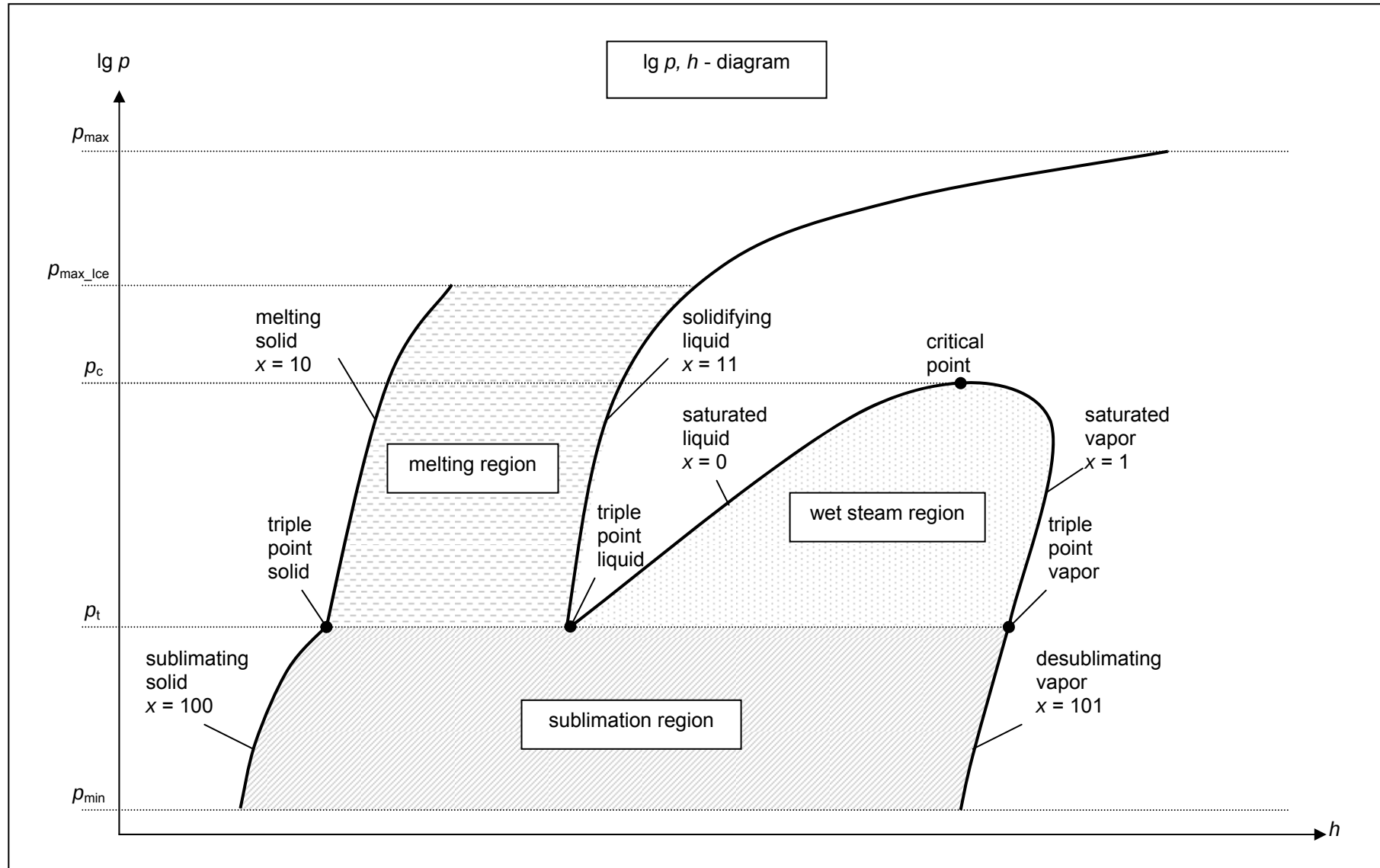
3.1 Ranges of Validity



Reference State:

At $p = 1.01325 \text{ bar}$ and $T = 298.15 \text{ K}$ (25°C):
 $h = -0.938457860 \text{ kJ/kg}$ and $s = -0.00219606205 \text{ kJ/(kg K)}$

Factor	Abbreviation	Value and Unit
Minimum temperature	$T_{\min} (t_{\min})$	85 K (-188.15°C)
Maximum temperature	$T_{\max} (t_{\max})$	1500 K (1226.85°C)
Triple temperature	$T_t (t_t)$	216.592 K (-56.558°C)
Temperature at the critical point	$T_c (t_c)$	304.1282 K (30.9782°C)
Maximum temperature of solid region	$T_{\max_ice} (t_{\max_ice})$	236.0309 K (-37.119°C)
Maximum temperature of melting pressure curve	$T_{\text{mel}}(p_{\max}) (t_{\text{mel}}(p_{\max}))$	327.671 K (54.521°C)
Minimum pressure	$p_{\min} = p_{\text{sub}}(T_{\min})$	$2.9081875815 \cdot 10^{-10} \text{ bar}$
Maximum pressure	$p_{\max}$	8000 bar
Triple pressure	p_t	5.179618369088 bar
Pressure at the critical point	p_c	73.773 bar
Maximum pressure of solid region	$p_{\max_ice}$	1000 bar



3.2 General Property Functions

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

Function Name: **a_ptx_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION APTXCO2(P,T,X)**
for call from Fortran **REAL*8 P,T,X**

Subprogram with parameter: **INTEGER*4 FUNCTION C_APTXCO2(A,P,T,X)**
for call from the DLL **REAL*8 A,P,T,X**

Input Values

P – Pressure p in bar
T - Temperature t in °C
X - x in kg / kg (Phase fraction, see the following explanations)

Result

APTXCO2, A or **a_ptx_CO2** – Thermal diffusivity $a = \frac{\lambda * v}{c_p}$ in m²/s

Range of Validity (cp. p, t -diagram in chapter 3.1)

Temperature range: from $t_{\min}$ to $t_{\max}$
 Pressure range: from $p_{\min}$ to $p_{\max}$ for liquid and steam
 from $p_{\min}$ to $p_{\max_Ice}$ for solid

Details on the phase fraction x

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

The two phase regions wet steam region, melting region and sublimation region are calculated automatically by the subprograms. For this purpose the following facts have to be considered (cp. p, h -diagram chapter 3.1):

1. Wet Vapor Region ($0 \leq x \leq 1$) :

The phase fraction x equates to the vapor fraction x in the wet steam region in (kg dry saturated steam)/(kg wet steam).

The calculation for x values between 0 and 1 is not possible.

If boiling liquid (boiling curve) is to be calculated, the value 0 has to be entered for x . In case of dry saturated steam (dew curve) $x = 1$ has to be entered.

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 0 or 1 for x must be entered when calculating boiling liquid or dry saturated steam. If p and t and x are entered, the program will consider p and t to represent the vapor pressure curve.

Boiling and dew curve: Temperature range from t_t to t_c
 Pressure range from p_t to p_c

2. Melting Region ($10 \leq x \leq 11$) :

The phase fraction x equates to the liquid fraction x in the melting region in (kg solidifying liquid)/(kg melt), whereas melt is a mixture of melting solid and solidifying liquid.

The calculation for x values between 10 and 11 is not possible.

If melting solid (melting curve) is to be calculated, the value 10 has to be entered for x . In case of solidifying liquid (solidification curve) $x = 11$ has to be entered.

When calculating a melting solid or solidifying liquid it is adequate, Concerning pressure and temperature, to put in either the value given for t and $p = -1000$ or the value given for p and $t = -1000$ and the value for x ($x = 10$ or $x = 11$). If p and t and x are entered as given values, the program tests whether p and t fulfil the melting pressure curve.

Melting curve: Temperature range from t_t to $t_{\max_Ice}$

Pressure range from p_t to $p_{\max_Ice}$

Solidification curve: Temperature range from t_t to $t_{\max}$

Pressure range from p_t to $p_{\max}$

Only the solidification curve ($x = 11$) is calculated for pressures p for which applies $p_{\max_Ice} < p \leq p_{\max}$.

3. Sublimation Region ($100 \leq x \leq 101$):

The phase fraction x equates to the vapour fraction x in the sublimation region in (kg desublimating steam)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating solid and desublimating steam.

The calculation for x values between 100 and 101 is not possible.

If sublimating solid is to be calculated, the value 100 has to be entered for x . In case of desublimating steam $x = 101$ has to be entered.

When calculating a sublimating solid or desublimating steam it is adequate, Concerning pressure and temperature, to put in either the value given for t and $p = -1000$ or the value given for p and $t = -1000$ and the value for x ($x = 100$ or $x = 101$). If p and t are entered as given values the program tests whether p and t fulfil the sublimation-pressure-curve.

Sublimation and

desublimation curve Temperatur range from $t_{\min}$ to t_t

Pressure range from $p_{\min}$ to p_t

Results for wrong input values

Result **APTXXCO2 = -1000, A = -1000** or **a_ptx_CO2 = -1000** for input values:

Single phase region:

Solid, liquid, overheated steam ($x = -1$):

- at $p < p_{\min}$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at Feststoff
- at $t < t_{\min}$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at Feststoff

Two phase regions:

Wet steam region ($0 \leq x \leq 1$):

- at $0 < x < 1$, i.e. calculation in the wet steam region not possible!
- at $p = -1000$ and $t < t_t$ or $t > t_c$
- at $t = -1000$ and $p < p_t$ or $p > p_c$
- at $p < p_t$ or $p > p_c$
- at $t < t_t$ or $t > t_c$

Melting region ($10 \leq x \leq 11$):

- at $10 < x < 11$, i.e. calculation in the melting region not possible!
- at $p = -1000$ and $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$
- at $t = -1000$ and $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$

Sublimation region ($100 \leq x \leq 101$):

- at $100 < x < 101$, i.e. calculation in the sublimation region not possible!
- at $p = -1000$ and $t < t_{\min}$ or $t > t_t$
- at $t = -1000$ and $p < p_{\min}$ or $p > p_t$
- at $p < p_{\min}$ or $p > p_t$
- at $t < t_{\min}$ or $t > t_t$

References: [2], [3]

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

Function Name: **cp_ptx_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION CPPTXCO2(P,T,X)**
for call from Fortran **REAL*8 P,T,X**

Subprogram with parameter: **INTEGER*4 FUNCTION C_CPPTXCO2(CP,P,T,X)**
for call from the DLL **REAL*8 CP,P,T,X**

Input Values

P – Pressure p in bar

T - Temperature t in °C

X - x in kg / kg (Phase fraction, see the following explanations)

Result

CPPTXCO2, CP or **cp_ptx_CO2** - specific isobaric heat capacity c_p in kJ/(kg K)

Range of Validity (cp. p, t -diagram in chapter 3.1)

Temperature range: from $t_{\min}$ to $t_{\max}$

Pressure range: from $p_{\min}$ to $p_{\max}$ for liquid and steam
from $p_{\min}$ to $p_{\max_Ice}$ for solid

Details on the phase fraction x

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

The two phase regions wet steam region, melting region and sublimation region are calculated automatically by the subprograms. For this purpose the following facts have to be considered (cp. lg p, h -diagram chapter 3.1):

1. Wet Vapor Region ($0 \leq x \leq 1$):

The phase fraction x equates to the vapor fraction x in the wet steam region in (kg dry saturated steam)/(kg wet steam).

The calculation for x values between 0 and 1 is not possible.

If boiling liquid (boiling curve) is to be calculated, the value 0 has to be entered for x . In case of dry saturated steam (dew curve) $x = 1$ has to be entered.

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 0 or 1 for x must be entered when calculating boiling liquid or dry saturated steam. If p and t and x are entered, the program will consider p and t to represent the vapor pressure curve.

Boiling and dew curve: Temperature range from t_t to t_c
Pressure range from p_t to p_c

2. Melting Region ($10 \leq x \leq 11$):

The phase fraction x equates to the liquid fraction x in the melting region in (kg solidifying liquid)/(kg melt), whereas melt is a mixture of melting solid and solidifying liquid.

The calculation for x values between 10 and 11 is not possible.

If melting solid (melting curve) is to be calculated, the value 10 has to be entered for x . In case of solidifying liquid (solidification curve) $x = 11$ has to be entered.

When calculating a melting solid or solidifying liquid it is adequate, Concerning pressure and temperature, to put in either the value given for t and $p = -1000$ or the value given for p and $t = -1000$ and the value for x ($x = 10$ or $x = 11$). If p and t and x are entered as given values, the program tests whether p and t fulfil the melting pressure curve.

Melting curve: Temperature range from t_t to $t_{\max_Ice}$
Pressure range from p_t to $p_{\max_Ice}$

Solidification curve: Temperature range from t_t to $t_{\max}$
Pressure range from p_t to $p_{\max}$

Only the solidification curve ($x = 11$) is calculated for pressures p for which applies $p_{\max_Ice} < p \leq p_{\max}$.

3. Sublimation Region ($100 \leq x \leq 101$):

The phase fraction x equates to the vapor fraction x in the sublimation region in (kg desublimating steam)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating solid and desublimating steam.

The calculation for x values between 100 and 101 is not possible.

If sublimating solid is to be calculated, the value 100 has to be entered for x . In case of desublimating steam $x = 101$ has to be entered.

When calculating a sublimating solid or desublimating steam it is adequate, Concerning pressure and temperature, to put in either the value given for t and $p = -1000$ or the value given for p and $t = -1000$ and the value for x ($x = 100$ or $x = 101$). If p and t and x are entered as given values the program tests whether p and t fulfil the sublimation-pressure-curve.

Sublimation and

desublimation curve Temperatur range from $t_{\min}$ to t_t

Pressure range from $p_{\min}$ to p_t

Results for wrong input values

Result **CPPTXCO2 = -1000, CP = -1000** or **cp_ptx_CO2 = -1000** for input values:

Single phase region:

Solid, liquid, overheated steam ($x = -1$):

- at $p < p_{\min}$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ when calculating solid
- at $t < t_{\min}$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ when calculating solid

Two phase regions:

Wet steam region ($0 \leq x \leq 1$):

- at $0 < x < 1$, i.e. calculation in the wet steam region not possible!
- at $p = -1000$ and $t < t_t$ or $t > t_c$
- at $t = -1000$ and $p < p_t$ or $p > p_c$
- at $p < p_t$ or $p > p_c$
- at $t < t_t$ or $t > t_c$

Melting region ($10 \leq x \leq 11$):

- at $10 < x < 11$, i.e. calculation in the melting region not possible!
- at $p = -1000$ and $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$
- at $t = -1000$ and $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$

Sublimation region ($100 \leq x \leq 101$):

- at $100 < x < 101$, i.e. calculation in the sublimation region not possible!
- at $p = -1000$ and $t < t_{\min}$ or $t > t_t$
- at $t = -1000$ and $p < p_{\min}$ or $p > p_t$
- at $p < p_{\min}$ or $p > p_t$
- at $t < t_{\min}$ or $t > t_t$

References: [2]

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

Function Name: **eta_ptx_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION ETAPTCO2(P,T,X)**
for call from Fortran **REAL*8 P,T,X**

Subprogram with parameter: **INTEGER*4 FUNCTION C_ETAPTCO2(ETA,P,T,X)**
for call from the DLL **REAL*8 ETA,P,T,X**

Input Values

P – Pressure p in bar
T - Temperature t in °C
X - x in kg / kg (Phase fraction, see the following explanations)

Result

ETAPTXCO2, ETA or **eta_ptx_CO2** – dynamic viscosity η in Pa s

Range of Validity (cp. p, t -diagram in chapter 3.1)

Temperature range: from t_t to $t_{\max}$
 Pressure range: from $p_{\min}$ to $p_{\max}$ for liquid and steam

Details on the phase fraction x

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. Calculating solid is not possible.

The two phase regions wet steam region, melting region and sublimation region are calculated automatically by the subprograms. For this purpose the following facts have to be considered (cp. lg p, h -diagram chapter 3.1):

1. Wet Vapor Region ($0 \leq x \leq 1$):

The phase fraction x equates to the vapor fraction x in the wet steam region in (kg dry saturated steam)/(kg wet steam).

The calculation for x values between 0 and 1 is not possible.

If boiling liquid (boiling curve) is to be calculated, the value 0 has to be entered for x . In case of dry saturated steam (dew curve) $x = 1$ has to be entered.

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 0 or 1 for x must be entered when calculating boiling liquid or dry saturated steam. If p and t and x are entered, the program will consider p and t to represent the vapor pressure curve.

Boiling and dew curve: Temperature range from t_t to t_c
 Pressure range from p_t to p_c

2. Melting Region ($10 \leq x \leq 11$):

The phase fraction x equates to the liquid fraction x in the melting region in (kg solidifying liquid)/(kg melt), whereas melt is a mixture of melting solid and solidifying liquid.

The calculation for x values of $x = 10$ (melting curve) and between 10 and 11 is not possible.

If solidifying liquid (solidification curve) is to be calculated, the value 11 has to be entered for x .

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 11 for x must be entered when calculating solidifying liquid. If p and t and x are entered as given values, the program tests whether p and t fulfil the melting pressure curve.

Melting curve: Temperature range from t_t to $t_{\max_Ice}$
 Pressure range from p_t to $p_{\max_Ice}$

Solidification curve: Temperature range from t_t to $t_{\max}$
 Pressure range from p_t to $p_{\max}$

3. Sublimation Region ($100 \leq x \leq 101$) :

The phase fraction x equates to the vapor fraction x in the sublimation region in (kg desublimating steam)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating solid and desublimating steam.

The calculation for x values of $x = 100$ (sublimation curve) and between 100 and 101 is not possible. If desublimating steam (desublimation curve) is to be calculated, the value 101 has to be entered for x . Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 101 for x must be entered when calculating desublimating steam. If p and t and x are entered as given values the program tests whether p and t fulfil the sublimation-pressure-curve.

Sublimation and

desublimation curve Temperatur range from $t_{\min}$ to t_t

Pressure range from $p_{\min}$ to p_t

Results for wrong input values

Result **ETAPTXCO2 = -1000**, **ETA = -1000** or **eta_ptx_CO2 = -1000** for input values:

Single phase region:

Liquid and overheated steam ($x = -1$):

- at $p < p_{\min}$ or $p > p_{\max}$
- at $t < t_{\min}$ or $t > t_{\max}$

Two phase regions:

Wet steam region ($0 \leq x \leq 1$):

- at $0 < x < 1$, i.e. calculation in the wet steam region not possible!
- at $p = -1000$ and $t < t_t$ or $t > t_c$
- at $t = -1000$ and $p < p_t$ or $p > p_c$
- at $p < p_t$ or $p > p_c$
- at $t < t_t$ or $t > t_c$

Melting region ($10 \leq x \leq 11$):

- at $10 < x < 11$, i.e. calculation on the melting curve and in the melting region not possible!
- at $p = -1000$ and $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$
- at $t = -1000$ and $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$

Sublimation region ($100 \leq x \leq 101$):

- at $100 \leq x < 101$, i.e. calculation on the sublimation curve and in the sublimation region not possible!
- at $p = -1000$ and $t < t_{\min}$ or $t > t_t$
- at $t = -1000$ and $p < p_{\min}$ or $p > p_t$
- at $p < p_{\min}$ or $p > p_t$
- at $t < t_{\min}$ or $t > t_t$

References: [2], [3]

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

Function Name: **h_ptx_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION HPTXCO2(P,T,X)**
for call from Fortran **REAL*8 P,T,X**

Subprogram with parameter: **INTEGER*4 FUNCTION C_HPTXCO2(H,P,T,X)**
for call from the DLL **REAL*8 H,P,T,X**

Input Values

P – Pressure p in bar

T - Temperature t in °C

X - x in kg / kg (Phase fraction, see the following explanations)

Result

HPTXCO2, H or h_ptx_CO2 - specific enthalpy h in kJ/kg

Range of Validity (cp. p, t -diagram in chapter 3.1)

Temperature range: from $t_{\min}$ to $t_{\max}$

Pressure range: from $p_{\min}$ to $p_{\max}$ for liquid and steam
from $p_{\min}$ to $p_{\max_ice}$ for solid

Details on the phase fraction x

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

The two phase regions wet steam region, melting region and sublimation region are calculated automatically by the subprograms. For this purpose the following facts have to be considered (cp. $\lg p, h$ -diagram chapter 3.1):

1. Wet Vapor Region ($0 \leq x \leq 1$):

The phase fraction x equates to the vapor fraction x in the wet steam region in (kg dry saturated steam)/(kg wet steam).

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

If boiling liquid (boiling curve) is to be calculated, the value 0 has to be entered for x . In case of dry saturated steam (dew curve) $x = 1$ has to be entered.

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 0 or 1 for x must be entered when calculating boiling liquid or dry saturated steam. If p and t and x are entered, the program will consider p and t to represent the vapor pressure curve.

Boiling and dew curve: Temperature range from t_t to t_c
Pressure range from p_t to p_c

2. Melting Region ($10 \leq x \leq 11$):

The phase fraction x equates to the liquid fraction x in the melting region in (kg solidifying liquid)/(kg melt), whereas melt is a mixture of melting solid and solidifying liquid.

If the state point to be calculated is located in the melting region, a value between 10 and 11 must be entered for x .

If melting solid (melting curve) is to be calculated, the value 10 has to be entered for x . In case of solidifying liquid (solidification curve) $x = 11$ has to be entered.

When calculating a melting solid or solidifying liquid it is adequate, Concerning pressure and temperature, to put in either the value given for t and $p = -1000$ or the value given for p and $t = -1000$ and the value for x ($x = 10$ or $x = 11$). If p and t and x are entered as given values, the program tests whether p and t fulfil the melting pressure curve.

Melting curve: Temperature range from t_t to $t_{\max_ice}$

Pressure range from p_t to $p_{\max_Ice}$

Solidification curve: Temperature range from t_t to $t_{\max}$

Pressure range from p_t to $p_{\max}$

Only the solidification curve ($x = 11$) is calculated for pressures p for which applies $p_{\max_Ice} < p \leq p_{\max}$.

3. Sublimation Region ($100 \leq x \leq 101$):

The phase fraction x equates to the vapor fraction x in the sublimation region in (kg desublimating steam)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating solid and desublimating steam.

If the state point to be calculated is located in the melting region, a value between 100 and 101 must be entered for x .

If sublimating solid is to be calculated, the value 100 has to be entered for x . In case of desublimating steam $x = 101$ has to be entered.

When calculating a sublimating solid or desublimating steam it is adequate, Concerning pressure and temperature, to put in either the value given for t and $p = -1000$ or the value given for p and $t = -1000$ and the value for x ($x = 100$ or $x = 101$). If p and t and x are entered as given values the program tests whether p and t fulfil the sublimation-pressure-curve.

Sublimation and

desublimation curve Temperatur range from $t_{\min}$ to t_t

Pressure range from $p_{\min}$ to p_t

Results for wrong input values

Result **HPTXCO2 = -1000, H = -1000** or **h_ptx_CO2 = -1000** for input values:

Single phase region:

Solid, liquid, overheated steam ($x = -1$):

- at $p < p_{\min}$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ when calculating solid
- at $t < t_{\min}$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ when calculating solid

Two phase regions:

Wet steam region ($0 \leq x \leq 1$):

- at $p = -1000$ and $t < t_t$ or $t > t_c$
- at $t = -1000$ and $p < p_t$ or $p > p_c$
- at $p < p_t$ or $p > p_c$
- at $t < t_t$ or $t > t_c$

Melting region ($10 \leq x \leq 11$):

- at $p = -1000$ and $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$
- at $t = -1000$ and $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$

Sublimation region ($100 \leq x \leq 101$):

- at $p = -1000$ and $t < t_{\min}$ or $t > t_t$
- at $t = -1000$ and $p < p_{\min}$ or $p > p_t$
- at $p < p_{\min}$ or $p > p_t$
- at $t < t_{\min}$ or $t > t_t$

References: [2]

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

Function Name: **kappa_ptx_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION KAPTXCO2(P,T,X)**
for call from Fortran **REAL*8 P,T,X**

Subprogram with parameter: **INTEGER*4 FUNCTION C_KAPTXCO2(KAP,P,T,X)**
for call from the DLL **REAL*8 KAP,P,T,X**

Input Values

P – Pressure p in bar

T - Temperature t in °C

X - x in kg / kg (Phase fraction, see the following explanations)

Result

KAP_PTX_CO2, KAP or kappa_ptx_CO2 – Isentropic exponent $\kappa = \frac{w^2}{p \cdot v}$

Range of Validity (cp. p,t -diagram in chapter 3.1)

Temperature range: from t_t to $t_{\max}$

Pressure range: from $p_{\min}$ to $p_{\max}$ for liquid and steam

Details on the phase fraction x

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. Calculating solid is not possible.

The two phase regions wet steam region, melting region and sublimation region are calculated automatically by the subprograms. For this purpose the following facts have to be considered (cp. lg p,h -diagram chapter 3.1):

1. Wet Vapor Region ($0 \leq x \leq 1$):

The phase fraction x equates to the vapor fraction x in the wet steam region in (kg dry saturated steam)/(kg wet steam).

The calculation for x values between 0 and 1 is not possible.

If boiling liquid (boiling curve) is to be calculated, the value 0 has to be entered for x . In case of dry saturated steam (dew curve) $x = 1$ has to be entered.

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 0 or 1 for x must be entered when calculating boiling liquid or dry saturated steam. If p and t and x are entered, the program will consider p and t to represent the vapor pressure curve.

Boiling and dew curve: Temperature range from t_t to t_c

Pressure range from p_t to p_c

2. Melting Region ($10 \leq x \leq 11$):

The phase fraction x equates to the liquid fraction x in the melting region in (kg solidifying liquid)/(kg melt), whereas melt is a mixture of melting solid and solidifying liquid.

The calculation for x values of $x = 10$ (melting curve) and between 10 and 11 is not possible.

If solidifying liquid (solidification curve) is to be calculated, the value 11 has to be entered for x .

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 11 for x must be entered when calculating solidifying liquid. If p and t and x are entered as given values, the program tests whether p and t fulfil the melting pressure curve.

Melting curve: Temperature range from t_t to $t_{\max_Ice}$

Pressure range from p_t to $p_{\max_Ice}$

Solidification curve: Temperature range from t_t to $t_{\max}$

Pressure range from p_t to $p_{\max}$

3. Sublimation Region ($100 \leq x \leq 101$) :

The phase fraction x equates to the vapor fraction x in the sublimation region in (kg desublimating steam)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating solid and desublimating steam.

The calculation for x values of $x = 100$ (sublimation curve) and between 100 and 101 is not possible. If desublimating steam (desublimation curve) is to be calculated, the value 101 has to be entered for x . Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 101 for x must be entered when calculating desublimating steam. If p and t and x are entered as given values the program tests whether p and t fulfil the sublimation-pressure-curve.

Sublimation and

desublimation curve Temperatur range from $t_{\min}$ to t_t

Pressure range from $p_{\min}$ to p_t

Results for wrong input values

Result KAP_PTX_CO2, KAP = -1000 or kappa_ptx_CO2 = -1000 for input values:

Single phase region:

Liquid and overheated steam ($x = -1$):

- at $p < p_{\min}$ or $p > p_{\max}$
- at $t < t_t$ or $t > t_{\max}$

Two phase regions:

Wet steam region ($0 \leq x \leq 1$):

- at $0 < x < 1$, i.e. calculation in the wet steam region not possible!
- at $p = -1000$ and $t < t_t$ or $t > t_c$
- at $t = -1000$ and $p < p_t$ or $p > p_c$
- at $p < p_t$ or $p > p_c$
- at $t < t_t$ or $t > t_c$

Melting region ($10 \leq x \leq 11$):

- at $10 < x < 11$, i.e. calculation on the melting curve and in the melting region not possible!
- at $p = -1000$ and $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$
- at $t = -1000$ and $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$

Sublimation region ($100 \leq x \leq 101$):

- at $100 \leq x < 101$, i.e. calculation on the sublimation curve and in the sublimation region not possible!
- at $p = -1000$ and $t < t_{\min}$ or $t > t_t$
- at $t = -1000$ and $p < p_{\min}$ or $p > p_t$
- at $p < p_{\min}$ or $p > p_t$
- at $t < t_{\min}$ or $t > t_t$

References: [2]

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

Function Name: **lambda_ptx_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION LAMPTCO2(P,T,X)**
for call from Fortran **REAL*8 P,T,X**

Subprogram with parameter: **INTEGER*4 FUNCTION C_LAMPTXCO2(LAM,P,T,X)**
for call from the DLL **REAL*8 LAM,P,T,X**

Input Values

P – Pressure p in bar

T - Temperature t in °C

X - x in kg / kg (Phase fraction, see the following explanations)

Result

LAMPTXCO2, LAM or **lambda_ptx_CO2** – Thermal conductivity λ in W/m K

Range of Validity (cp. p, t -diagram in chapter 3.1)

Temperature range: from $t_{\min}$ to $t_{\max}$

Pressure range: from $p_{\min}$ to $p_{\max}$ for liquid and steam
from $p_{\min}$ to $p_{\max_Ice}$ for solid

Details on the phase fraction x

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

The two phase regions wet steam region, melting region and sublimation region are calculated automatically by the subprograms. For this purpose the following facts have to be considered (cp. lg p, h -diagram chapter 3.1):

1. Wet Vapor Region ($0 \leq x \leq 1$):

The phase fraction x equates to the vapor fraction x in the wet steam region in (kg dry saturated steam)/(kg wet steam).

The calculation for x values between 0 and 1 is not possible.

If boiling liquid (boiling curve) is to be calculated, the value 0 has to be entered for x . In case of dry saturated steam (dew curve) $x = 1$ has to be entered.

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 0 or 1 for x must be entered when calculating boiling liquid or dry saturated steam. If p and t and x are entered, the program will consider p and t to represent the vapor pressure curve.

Boiling and dew curve: Temperature range from t_t to t_c

Pressure range from p_t to p_c

2. Melting Region ($10 \leq x \leq 11$):

The phase fraction x equates to the liquid fraction x in the melting region in (kg solidifying liquid)/(kg melt), whereas melt is a mixture of melting solid and solidifying liquid.

The calculation for x values between 10 and 11 is not possible.

If melting solid (melting curve) is to be calculated, the value 10 has to be entered for x . In case of solidifying liquid (solidification curve) $x = 11$ has to be entered.

When calculating a melting solid or solidifying liquid it is adequate, Concerning pressure and temperature, to put in either the value given for t and $p = -1000$ or the value given for p and $t = -1000$ and the value for x ($x = 10$ or $x = 11$). If p and t and x are entered as given values, the program tests whether p and t fulfil the melting pressure curve.

Melting curve: Temperature range from t_t to $t_{\max_Ice}$

Pressure range from p_t to $p_{\max_Ice}$

Solidification curve: Temperature range from t_t to $t_{\max}$
 Pressure range from p_t to $p_{\max}$

Only the solidification curve ($x = 11$) is calculated for pressures p for which applies $p_{\max_Ice} < p \leq p_{\max}$.

3. Sublimation Region ($100 \leq x \leq 101$):

The phase fraction x equates to the vapor fraction x in the sublimation region in (kg desublimating steam)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating solid and desublimating steam.

The calculation for x values between 100 and 101 is not possible.

If sublimating solid is to be calculated, the value 100 has to be entered for x . In case of desublimating steam $x = 101$ has to be entered.

When calculating a sublimating solid or desublimating steam it is adequate, Concerning pressure and temperature, to put in either the value given for t and $p = -1000$ or the value given for p and $t = -1000$ and the value for x ($x = 100$ or $x = 101$). If p and t and x are entered as given values the program tests whether p and t fulfil the sublimation-pressure-curve.

Sublimation and

desublimation curve Temperatur range from $t_{\min}$ to t_t
 Pressure range from $p_{\min}$ to p_t

Results for wrong input values

Result LAMPTXCO2 = - 1000, LAM = -1000 or lambda_ptx_CO2 = - 1000 for input values:

Single phase region:

Solid, liquid, overheated steam ($x = -1$):

- at $p < p_{\min}$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ when calculating solid
- at $t < t_{\min}$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ when calculating solid

Two phase regions:

Wet steam region ($0 \leq x \leq 1$):

- at $0 < x < 1$, i.e. calculation in the wet steam region not possible!
- at $p = -1000$ and $t < t_t$ or $t > t_c$
- at $t = -1000$ and $p < p_t$ or $p > p_c$
- at $p < p_t$ or $p > p_c$
- at $t < t_t$ or $t > t_c$

Melting region ($10 \leq x \leq 11$):

- at $10 < x < 11$, i.e. calculation in the melting region not possible!
- at $p = -1000$ and $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$
- at $t = -1000$ and $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$

Sublimation region ($100 \leq x \leq 101$):

- at $100 < x < 101$, i.e. calculation in the sublimation region not possible!
- at $p = -1000$ and $t < t_{\min}$ or $t > t_t$
- at $t = -1000$ and $p < p_{\min}$ or $p > p_t$
- at $p < p_{\min}$ or $p > p_t$
- at $t < t_{\min}$ or $t > t_t$

References: [2], [3]

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

Function Name: **ny_ptx_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION NYPTXCO2(P,T,X)**
for call from Fortran **REAL*8 P,T,X**

Subprogram with parameter: **INTEGER*4 FUNCTION C_NYPTXCO2(NY,P,T,X)**
for call from the DLL **REAL*8 NY,P,T,X**

Input Values

P – Pressure p in bar

T - Temperature t in °C

X - x in kg / kg (Phase fraction, see the following explanations)

Result

NYPTXCO2, NY or ny_ptx_CO2 – Kinematic viscosity $\nu = \eta * \nu$ in m^2/s

Range of Validity (cp. p, t -diagram in chapter 3.1)

Temperature range: from t_t to $t_{\max}$

Pressure range: from $p_{\min}$ to $p_{\max}$ for liquid and steam

Details on the phase fraction x

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. Calculating solid is not possible.

The two phase regions wet steam region, melting region and sublimation region are calculated automatically by the subprograms. For this purpose the following facts have to be considered (cp. $\lg p, h$ -diagram chapter 3.1):

1. Wet Vapor Region ($0 \leq x \leq 1$):

The phase fraction x equates to the vapor fraction x in the wet steam region in (kg dry saturated steam)/(kg wet steam).

The calculation for x values between 0 and 1 is not possible.

If boiling liquid (boiling curve) is to be calculated, the value 0 has to be entered for x . In case of dry saturated steam (dew curve) $x = 1$ has to be entered.

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 0 or 1 for x must be entered when calculating boiling liquid or dry saturated steam. If p and t and x are entered, the program will consider p and t to represent the vapor pressure curve.

Boiling and dew curve: Temperature range from t_t to t_c

Pressure range from p_t to p_c

2. Melting Region ($10 \leq x \leq 11$):

The phase fraction x equates to the liquid fraction x in the melting region in (kg solidifying liquid)/(kg melt), whereas melt is a mixture of melting solid and solidifying liquid.

The calculation for x values of $x = 10$ (melting curve) and between 10 and 11 is not possible.

If solidifying liquid (solidification curve) is to be calculated, the value 11 has to be entered for x .

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 11 for x must be entered when calculating solidifying liquid. If p and t and x are entered as given values, the program tests whether p and t fulfil the melting pressure curve.

Melting curve: Temperature range from t_t to $t_{\max_Ice}$

Pressure range from p_t to $p_{\max_Ice}$

Solidification curve: Temperature range from t_t to $t_{\max}$

Pressure range from p_t to $p_{\max}$

3. Sublimation Region ($100 \leq x \leq 101$) :

The phase fraction x equates to the vapor fraction x in the sublimation region in (kg desublimating steam)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating solid and desublimating steam.

The calculation for x values of $x = 100$ (sublimation curve) and between 100 and 101 is not possible. If desublimating steam (desublimation curve) is to be calculated, the value 101 has to be entered for x . Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 101 for x must be entered when calculating desublimating steam. If p and t and x are entered as given values the program tests whether p and t fulfil the sublimation-pressure-curve.

Sublimation and

desublimation curve Temperatur range from $t_{\min}$ to t_t

Pressure range from $p_{\min}$ to p_t

Results for wrong input values

Result NYPTXCO2 = -1000, NY = -1000 or ny_ptx_CO2 = -1000 for input values:

Single phase region:

Liquid and overheated steam ($x = -1$):

- at $p < p_{\min}$ or $p > p_{\max}$
- at $t < t_t$ or $t > t_{\max}$

Two phase regions:

Wet steam region ($0 \leq x \leq 1$):

- at $0 < x < 1$, i.e. calculation in the wet steam region not possible!
- at $p = -1000$ and $t < t_t$ or $t > t_c$
- at $t = -1000$ and $p < p_t$ or $p > p_c$
- at $p < p_t$ or $p > p_c$
- at $t < t_t$ or $t > t_c$

Melting region ($10 \leq x \leq 11$):

- at $10 < x < 11$, i.e. calculation on the melting curve and in the melting region not possible!
- at $p = -1000$ and $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$
- at $t = -1000$ and $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$

Sublimation region ($100 \leq x \leq 101$):

- at $100 \leq x < 101$, i.e. calculation on the sublimation curve and in the sublimation region not possible!
- at $p = -1000$ and $t < t_{\min}$ or $t > t_t$
- at $t = -1000$ and $p < p_{\min}$ or $p > p_t$
- at $p < p_{\min}$ or $p > p_t$
- at $t < t_{\min}$ or $t > t_t$

References: [2], [3]

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

Function Name: **pmel_t_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION PMELCO2(T)**
 for call from Fortran **REAL*8 T**

Subprogram with parameter: **INTEGER*4 FUNCTION C_PMELCO2(PMEL,T)**
 for call from the DLL **REAL*8 PMEL,P,T,X**

Input Values

T - Temperature t in °C

Result

PMELCO2, PMEL or **pmel_t_CO2** – Melting pressure p_{mel} in bar

Range of Validity (cp. p,t -diagram in chapter 3.1)

Temperature range: from t_t to $t_{\text{mel}}(p_{\text{max}})$

Results for wrong input values

Result **PMELCO2 = -1000, PMEL = -1000** or **pmel_t_CO2 = -1000** for input values:

- at $t < t_t$ or $t > t_{\text{mel}}(p_{\text{max}})$

References: [2]

Sublimation Pressure $p_{\text{sub}} = f(t)$

Function Name: **psub_t_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION PSUBCO2(T)**
 for call from Fortran **REAL*8 T**

Subprogram with parameter: **INTEGER*4 FUNCTION C_PSUBCO2(PSUB,T)**
 for call from the DLL **REAL*8 PSUB,P,T,X**

Input Values

T - Temperature t in °C

Result

PSUBCO2, PSUB or **psub_t_CO2** – Sublimation pressure p_{sub} in bar

Range of Validity (cp. p,t -diagram in chapter 3.1)

Temperature range: from t_{min} to t_t

Results for wrong input values

Result **PSUBCO2 = -1000, PSUB = -1000** or **psub_t_CO2 = -1000** for input values:

- at $t < t_{\text{min}}$ or $t > t_c$

References: [2]

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

Function Name: **Pr_ptx_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION PRPTXCO2(P,T,X)**
for call from Fortran **REAL*8 P,T,X**

Subprogram with parameter: **INTEGER*4 FUNCTION C_PRPTXCO2(PR,P,T,X)**
for call from the DLL **REAL*8 PR,P,T,X**

Input Values

P – Pressure p in bar

T - Temperature t in °C

X - x in kg / kg (Phase fraction, see the following explanations)

Result

PRPTXCO2, PR or Pr_ptx_CO2 – Prandtl-Number $Pr = \frac{\eta * c_p}{\lambda}$

Range of Validity (cp. p, t -diagram in chapter 3.1)

Temperature range: from t_t to $t_{\max}$

Pressure range: from $p_{\min}$ to $p_{\max}$ for liquid and steam

Details on the phase fraction x

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. Calculating solid is not possible.

The two phase regions wet steam region, melting region and sublimation region are calculated automatically by the subprograms. For this purpose the following facts have to be considered (cp. $\lg p, h$ -diagram chapter 3.1):

1. Wet Vapor Region ($0 \leq x \leq 1$):

The phase fraction x equates to the vapor fraction x in the wet steam region in (kg dry saturated steam)/(kg wet steam).

The calculation for x values between 0 and 1 is not possible.

If boiling liquid (boiling curve) is to be calculated, the value 0 has to be entered for x . In case of dry saturated steam (dew curve) $x = 1$ has to be entered.

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 0 or 1 for x must be entered when calculating boiling liquid or dry saturated steam. If p and t and x are entered, the program will consider p and t to represent the vapor pressure curve.

Boiling and dew curve: Temperature range from t_t to t_c

Pressure range from p_t to p_c

2. Melting Region ($10 \leq x \leq 11$):

The phase fraction x equates to the liquid fraction x in the melting region in (kg solidifying liquid)/(kg melt), whereas melt is a mixture of melting solid and solidifying liquid.

The calculation for x values of $x = 10$ (melting curve) and between 10 and 11 is not possible.

If solidifying liquid (solidification curve) is to be calculated, the value 11 has to be entered for x .

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 11 for x must be entered when calculating solidifying liquid. If p and t and x are entered as given values, the program tests whether p and t fulfil the melting pressure curve.

Melting curve: Temperature range from t_t to $t_{\max_Ice}$

Pressure range from p_t to $p_{\max_Ice}$

Solidification curve: Temperature range from t_t to $t_{\max}$

Pressure range from p_t to $p_{\max}$

3. Sublimation Region ($100 \leq x \leq 101$) :

The phase fraction x equates to the vapor fraction x in the sublimation region in (kg desublimating steam)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating solid and desublimating steam.

The calculation for x values of $x = 100$ (sublimation curve) and between 100 and 101 is not possible. If desublimating steam (desublimation curve) is to be calculated, the value 101 has to be entered for x . Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 101 for x must be entered when calculating desublimating steam. If p and t and x are entered as given values the program tests whether p and t fulfil the sublimation-pressure-curve.

Sublimation and

desublimation curve Temperatur range from $t_{\min}$ to t_t

Pressure range from $p_{\min}$ to p_t

Results for wrong input values

Result **PRPTXCO2 = -1000**, **PR = -1000** or **Pr_ptx_CO2 = -1000** for input values:

Single phase region:

Liquid and overheated steam ($x = -1$):

- at $p < p_{\min}$ or $p > p_{\max}$
- at $t < t_t$ or $t > t_{\max}$

Two phase regions:

Wet steam region ($0 \leq x \leq 1$):

- at $0 < x < 1$, i.e. calculation in the wet steam region not possible!
- at $p = -1000$ and $t < t_t$ or $t > t_c$
- at $t = -1000$ and $p < p_t$ or $p > p_c$
- at $p < p_t$ or $p > p_c$
- at $t < t_t$ or $t > t_c$

Melting region ($10 \leq x \leq 11$):

- at $10 < x < 11$, i.e. calculation on the melting curve and in the melting region not possible!
- at $p = -1000$ and $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$
- at $t = -1000$ and $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$

Sublimation region ($100 \leq x \leq 101$):

- at $100 \leq x < 101$, i.e. calculation on the sublimation curve and in the sublimation region not possible!
- at $p = -1000$ and $t < t_{\min}$ or $t > t_t$
- at $t = -1000$ and $p < p_{\min}$ or $p > p_t$
- at $p < p_{\min}$ or $p > p_t$
- at $t < t_{\min}$ or $t > t_t$

References: [2], [3]

Vapor Pressure $p_s = f(t)$

Function Name: **ps_t_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION PSTCO2(T)**
 for call from Fortran **REAL*8 T**

Subprogram with parameter: **INTEGER*4 FUNCTION C_PSTCO2(PS,T)**
 for call from the DLL **REAL*8 PS,T**

Input Values

T - Temperature t in °C

Result

PSTCO2, PS or **ps_t_CO2** – Vapor pressure p_s in bar

Range of Validity (cp. p,t -diagram in chapter 3.1)

Temperature range: from t_t to t_c

Results for wrong input values

Result **PSTCO2 = -1000, PS = -1000** or **ps_t_CO2 = -1000** for input values:

- at $t < t_t$ or $t > t_c$

References: [2]

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

Function Name: **rho_ptx_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION ROPTXCO2(P,T,X)**
for call from Fortran **REAL*8 P,T,X**

Subprogram with parameter: **INTEGER*4 FUNCTION C_ROPTXCO2(RHO,P,T,X)**
for call from the DLL **REAL*8 RHO,P,T,X**

Input Values

P – Pressure p in bar

T - Temperature t in °C

X - x in kg / kg (Phase fraction, see the following explanations)

Result

RHO_PTX_CO2, RHO or **rho_ptx_CO2** - Density ρ in kg/m³

Range of Validity (cp. p, t -diagram in chapter 3.1)

Temperature range: from $t_{\min}$ to $t_{\max}$

Pressure range: from $p_{\min}$ to $p_{\max}$ for liquid and steam
from $p_{\min}$ to $p_{\max_Ice}$ for solid

Details on the phase fraction x

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

The two phase regions wet steam region, melting region and sublimation region are calculated automatically by the subprograms. For this purpose the following facts have to be considered (cp. lg p, h -diagram chapter 3.1):

1. Wet Vapor Region ($0 \leq x \leq 1$):

The phase fraction x equates to the vapor fraction x in the wet steam region in (kg dry saturated steam)/(kg wet steam).

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

If boiling liquid (boiling curve) is to be calculated, the value 0 has to be entered for x . In case of dry saturated steam (dew curve) $x = 1$ has to be entered.

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 0 or 1 for x must be entered when calculating boiling liquid or dry saturated steam. If p and t and x are entered, the program will consider p and t to represent the vapor pressure curve.

Boiling and dew curve: Temperature range from t_t to t_c

Pressure range from p_t to p_c

2. Melting Region ($10 \leq x \leq 11$):

The phase fraction x equates to the liquid fraction x in the melting region in (kg solidifying liquid)/(kg melt), whereas melt is a mixture of melting solid and solidifying liquid.

If the state point to be calculated is located in the melting region, a value between 10 and 11 must be entered for x .

If melting solid (melting curve) is to be calculated, the value 10 has to be entered for x . In case of solidifying liquid (solidification curve) $x = 11$ has to be entered.

When calculating a melting solid or solidifying liquid it is adequate, Concerning pressure and temperature, to put in either the value given for t and $p = -1000$ or the value given for p and $t = -1000$ and the value for x ($x = 10$ or $x = 11$). If p and t and x are entered as given values, the program tests whether p and t fulfil the melting pressure curve.

Melting curve: Temperature range from t_t to $t_{\max_Ice}$

Pressure range from p_t to $p_{\max_Ice}$

Solidification curve: Temperature range from t_t to $t_{\max}$
 Pressure range from p_t to $p_{\max}$

Only the solidification curve ($x = 11$) is calculated for pressures p for which applies $p_{\max_Ice} < p \leq p_{\max}$.

3. Sublimation Region ($100 \leq x \leq 101$):

The phase fraction x equates to the vapor fraction x in the sublimation region in (kg desublimating steam)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating solid and desublimating steam.

If the state point to be calculated is located in the melting region, a value between 100 and 101 must be entered for x .

If sublimating solid is to be calculated, the value 100 has to be entered for x . In case of desublimating steam $x = 101$ has to be entered.

When calculating a sublimating solid or desublimating steam it is adequate, Concerning pressure and temperature, to put in either the value given for t and $p = -1000$ or the value given for p and $t = -1000$ and the value for x ($x = 100$ or $x = 101$). If p and t are entered as given values the program tests whether p and t fulfil the sublimation-pressure-curve.

Sublimation and

desublimation curve Temperatur range from $t_{\min}$ to t_t
 Pressure range from $p_{\min}$ to p_t

Results for wrong input values

Result **RHOPTXCO2 = - 1000**, **RHO = -1000** or **rho_ptx_CO2 = - 1000** for input values:

Single phase region:

Solid, liquid, overheated steam ($x = -1$):

- at $p < p_{\min}$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ when calculating solid
- at $t < t_{\min}$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ when calculating solid

Two phase regions:

Wet steam region ($0 \leq x \leq 1$):

- at $p = -1000$ and $t < t_t$ or $t > t_c$
- at $t = -1000$ and $p < p_t$ or $p > p_c$
- at $p < p_t$ or $p > p_c$
- at $t < t_t$ or $t > t_c$

Melting region ($10 \leq x \leq 11$):

- at $p = -1000$ and $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$
- at $t = -1000$ and $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$

Sublimation region ($100 \leq x \leq 101$):

- at $p = -1000$ and $t < t_{\min}$ or $t > t_t$
- at $t = -1000$ and $p < p_{\min}$ or $p > p_t$
- at $p < p_{\min}$ or $p > p_t$
- at $t < t_{\min}$ or $t > t_t$

References: [2]

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

Function Name: **s_ptx_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION SPTXCO2(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Subprogram with parameter: **INTEGER*4 FUNCTION C_SPTXCO2(S,P,T,X)**
 for call from the DLL **REAL*8 S,P,T,X**

Input Values

P – Pressure p in bar
T - Temperature t in °C
X - x in kg / kg (Phase fraction, see the following explanations)

Result

SPTXCO2, S or s_ptx_CO2 - Specific entropy s in kJ/kg K

Range of Validity (cp. p, t -diagram in chapter 3.1)

Temperature range: from $t_{\min}$ to $t_{\max}$
 Pressure range: from $p_{\min}$ to $p_{\max}$ for liquid and steam
 from $p_{\min}$ to $p_{\max_Ice}$ for solid

Details on the phase fraction x

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

The two phase regions wet steam region, melting region and sublimation region are calculated automatically by the subprograms. For this purpose the following facts have to be considered (cp. $\lg p, h$ -diagram chapter 3.1):

1. Wet Vapor Region ($0 \leq x \leq 1$) :

The phase fraction x equates to the vapor fraction x in the wet steam region in (kg dry saturated steam)/(kg wet steam).

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

If boiling liquid (boiling curve) is to be calculated, the value 0 has to be entered for x . In case of dry saturated steam (dew curve) $x = 1$ has to be entered.

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 0 or 1 for x must be entered when calculating boiling liquid or dry saturated steam. If p and t and x are entered, the program will consider p and t to represent the vapor pressure curve.

Boiling and dew curve: Temperature range from t_t to t_c
 Pressure range from p_t to p_c

2. Melting Region ($10 \leq x \leq 11$) :

The phase fraction x equates to the liquid fraction x in the melting region in (kg solidifying liquid)/(kg melt), whereas melt is a mixture of melting solid and solidifying liquid.

If the state point to be calculated is located in the melting region, a value between 10 and 11 must be entered for x .

If melting solid (melting curve) is to be calculated, the value 10 has to be entered for x . In case of solidifying liquid (solidification curve) $x = 11$ has to be entered.

When calculating a melting solid or solidifying liquid it is adequate, concerning pressure and temperature, to put in either the value given for t and $p = -1000$ or the value given for p and $t = -1000$ and the value for x ($x = 10$ or $x = 11$). If p and t and x are entered as given values the program tests whether p and t fulfil the melting pressure curve.

Melting curve: Temperature range from t_t to $t_{\max_Ice}$
 Pressure range from p_t to $p_{\max_Ice}$

Solidification curve: Temperature range from t_t to $t_{\max}$
 Pressure range from p_t to $p_{\max}$

Only the solidification curve ($x = 11$) is calculated for pressures p for which applies $p_{\max_Ice} < p \leq p_{\max}$.

3. Sublimation Region ($100 \leq x \leq 101$):

The phase fraction x equates to the vapor fraction x in the sublimation region in (kg desublimating steam)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating solid and desublimating steam.

If the state point to be calculated is located in the melting region, a value between 100 and 101 must be entered for x .

If sublimating solid is to be calculated, the value 100 has to be entered for x . In case of desublimating steam $x = 101$ has to be entered.

When calculating a sublimating solid or desublimating steam it is adequate, Concerning pressure and temperature, to put in either the value given for t and $p = -1000$ or the value given for p and $t = -1000$ and the value for x ($x = 100$ or $x = 101$). If p and t and x are entered as given values the program tests whether p and t fulfil the sublimation-pressure-curve.

Sublimation and

desublimation curve Temperatur range from $t_{\min}$ to t_t
 Pressure range from $p_{\min}$ to p_t

Results for wrong input values

Result **SPTXCO2 = -1000, S = -1000** or **s_ptx_CO2 = -1000** for input values:

Single phase region:

Solid, liquid, overheated steam ($x = -1$):

- at $p < p_{\min}$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ when calculating solid
- at $t < t_{\min}$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ when calculating solid

Two phase regions:

Wet steam region ($0 \leq x \leq 1$):

- at $p = -1000$ and $t < t_t$ or $t > t_c$
- at $t = -1000$ and $p < p_t$ or $p > p_c$
- at $p < p_t$ or $p > p_c$
- at $t < t_t$ or $t > t_c$

Melting region ($10 \leq x \leq 11$):

- at $p = -1000$ and $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$
- at $t = -1000$ and $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$

Sublimation region ($100 \leq x \leq 101$):

- at $p = -1000$ and $t < t_{\min}$ or $t > t_t$
- at $t = -1000$ and $p < p_{\min}$ or $p > p_t$
- at $p < p_{\min}$ or $p > p_t$
- at $t < t_{\min}$ or $t > t_t$

References: [2]

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

Function Name: **t_ph_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION TPHCO2(P,H)**
 for call from Fortran **REAL*8 P,H**

Subprogram with parameter: **INTEGER*4 FUNCTION C_TPHCO2(T,P,H)**
 for call from the DLL **REAL*8 T,P,H**

Input Values

P – Pressure p in bar
H - Specific enthalpy h in kJ/kg

Result

TPHCO2, T or t_ph_CO2 – Temperature t in °C

Range of Validity (cp. p, t -diagram in chapter 3.1)

Pressure range: from $p_{\min}$ to $p_{\max}$ for liquid and steam
 from $p_{\min}$ to $p_{\max_Ice}$ for solid

Enthalpy range: from $h < h_{\max} = h(p_{\min}, t_{\max})$ to $h > h_{\min} = h(p_{\min}, t_{\min})$

Temperature range: from $t_{\min}$ to $t_{\max}$ (resulting from internal calculation of the subprograms)

Details on calculating the two phase regions

Using the given values for p and h , the program determines whether the point of state to be calculated is located in the single phase region (solid, liquid or steam) or in the two phase region. The two phase regions wet steam region, melting region and sublimation region (cp. lg p, h -diagram chapter 3.1) are calculated automatically by the subprograms. After that, the calculation is realized for the certain region.

Results for wrong input values

Result **T_PH_CO2, T = -1000** or **t_ph_CO2 = -1000** for input values:

Single phase region:

Solid, liquid, overheated steam:
 - at $p < p_{\min}$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ when calculating solid
 - at calculation result $t < t_{\min}$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ when calculating solid

Two phase regions:

Wet steam region:
 - at $p < p_t$ or $p > p_c$
 - at calculation result $t < t_t$ or $t > t_c$

Melting region:

- at $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ when calculating solid
 - at calculation result $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ when calculating solid

Sublimation region:

- at $p < p_{\min}$ or $p > p_t$
 - at calculation result $t < t_{\min}$ or $t > t_t$

References: [2]

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

Function Name: **t_ps_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION TPSCO2(P,S)**
for call from Fortran **REAL*8 P,S**

Subprogram with parameter: **INTEGER*4 FUNCTION C_TPSCO2(T,P,S)**
for call from the DLL **REAL*8 T,P,S**

Input Values

P – Pressure p in bar

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

Result

TPSCO2, T or t_ps_CO2 – Temperature t in °C

Range of Validity (cp. p,t -diagram in chapter 3.1)

Pressure range: from $p_{\min}$ to $p_{\max}$ for liquid and steam
from $p_{\min}$ to $p_{\max_Ice}$ for solid

Entropy range: from $s < s_{\max} = s(p_{\min}, t_{\max})$ to $s > s_{\min} = s(p_{\min}, t_{\min})$

Temperature range: from $t_{\min}$ to $t_{\max}$ (resulting from internal calculation of the subprograms)

Details on calculating the two phase regions

Using the given values for p and h , the program determines whether the point of state to be calculated is located in the single phase region (solid, liquid or steam) or in the two phase region. The two phase regions wet steam region, melting region and sublimation region (cp. lg p,h -diagram chapter 3.1) are calculated automatically by the subprograms. After that, the calculation is realized for the certain region.

Results for wrong input values

Result **T_PS_CO2, T = -1000** or **t_ps_CO2 = -1000** for input values:

Single phase region:

Solid, liquid, overheated steam:

- at $p < p_{\min}$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ when calculating solid
- at calculation result $t < t_{\min}$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ when calculating solid

Two phase regions:

Wet steam region:

- at $p < p_t$ or $p > p_c$
- at calculation result $t < t_t$ or $t > t_c$

Melting region:

- at $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ when calculating solid
- at calculation result $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ when calculating solid

Sublimation region:

- at $p < p_{\min}$ or $p > p_t$
- at calculation result $t < t_{\min}$ or $t > t_t$

References: [2]

Saturation Temperature $t_s = f(p)$

Function Name: **ts_p_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION TSPCO2(P)**
for call from Fortran **REAL*8 P**

Subprogram with parameter: **INTEGER*4 FUNCTION C_TSPCO2(TS,P)**
for call from the DLL **REAL*8 TS,P**

Input Values

P – Pressure p in bar

Result

TSPCO2, TS or ts_p_CO2 – Saturation temperature t_s in °C

Range of Validity (cp. p, t -diagram in chapter 3.1)

Pressure range: from p_t to p_c

Results for wrong input values

Result **TSPCO2 = -1000, TS = -1000 or ts_p_CO2 = -1000** for input values:

- at $p < p_t$ or $p > p_c$

References: [2]

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

Function Name: **tmel_p_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION TMELCO2(P)**
for call from Fortran **REAL*8 P**

Subprogram with parameter: **INTEGER*4 FUNCTION C_TMELCO2(TMEL,P)**
for call from the DLL **REAL*8 TMEL,P**

Input Values

P – Pressure p in bar

Result

TMELCO2, TMEL or **tmel_p_CO2** – Melting temperature t_{mel} in °C

Range of Validity (cp. p, t -diagram in chapter 3.1)

Pressure range: from p_t to p_{max}

Results for wrong input values

Result **TMELCO2 = -1000**, **TMEL = -1000** or **tmel_p_CO2 = -1000** for input values:

- at $p < p_t$ or $p > p_{\text{max}}$

References: [2]

Sublimation Temperature $t_{\text{sub}} = f(p)$

Function Name: **tsub_p_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION TSUBCO2(P)**
 for call from Fortran **REAL*8 P**

Subprogram with parameter: **INTEGER*4 FUNCTION C_TSUBCO2(TSUB,P)**
 for call from the DLL **REAL*8 TSUB,P**

Input Values

P – Pressure p in bar

Result

TSUBCO2, TSUB or **tsub_p_CO2** – Sublimation temperature t_{sub} in °C

Range of Validity (cp. p, t -diagram in chapter 3.1)

Pressure range: from p_{min} to p_t

Results for wrong input values

Result **TSUBCO2, = -1000, TSUB = -1000** or **tsub_p_CO2 = -1000** for input values:

- at $p < p_{\text{min}}$ or $p > p_t$

References: [2]

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

Function Name: **v_ptx_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION VPTXCO2(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Subprogram with parameter: **INTEGER*4 FUNCTION C_VPTXCO2(V,P,T,X)**
 for call from the DLL **REAL*8 V,P,T,X**

Input Values

P – Pressure p in bar
T - Temperature t in °C
X - x in kg / kg (Phase fraction, see the following explanations)

Result

VPTXCO2, V or v_ptx_CO2 – Specific volume v in m³/kg

Range of Validity (cp. p, t -diagram in chapter 3.1)

Temperature range: from $t_{\min}$ to $t_{\max}$
 Pressure range: from $p_{\min}$ to $p_{\max}$ for liquid and steam
 from $p_{\min}$ to $p_{\max_Ice}$ for solid

Details on the phase fraction x

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

The two phase regions wet steam region, melting region and sublimation region are calculated automatically by the subprograms. For this purpose the following facts have to be considered (cp. lg p, h -diagram chapter 3.1):

1. Wet Vapor Region ($0 \leq x \leq 1$):

The phase fraction x equates to the vapor fraction x in the wet steam region in (kg dry saturated steam)/(kg wet steam).

If boiling liquid (boiling curve) is to be calculated, the value 0 has to be entered for x . In case of dry saturated steam (dew curve) $x = 1$ has to be entered.

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

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 0 or 1 for x must be entered when calculating boiling liquid or dry saturated steam. If p and t and x are entered, the program will consider p and t to represent the vapor pressure curve.

Boiling and dew curve: Temperature range from t_t to t_c

Pressure range from p_t to p_c

2. Melting Region ($10 \leq x \leq 11$):

The phase fraction x equates to the liquid fraction x in the melting region in (kg solidifying liquid)/(kg melt), whereas melt is a mixture of melting solid and solidifying liquid.

If melting solid (melting curve) is to be calculated, the value 10 has to be entered for x . In case of solidifying liquid (solidification curve) $x = 11$ has to be entered.

If the state point to be calculated is located in the melting region, a value between 10 and 11 must be entered for x .

When calculating a melting solid or solidifying liquid it is adequate, concerning pressure and temperature, to put in either the value given for t and $p = -1000$ or the value given for p and $t = -1000$ and the value for x ($x = 10$ or $x = 11$). If p and t and x are entered as given values the program tests whether p and t fulfil the melting pressure curve.

Melting curve: Temperature range from t_t to $t_{\max_Ice}$

Pressure range from p_t to $p_{\max_Ice}$

Solidification curve: Temperature range from t_t to $t_{\max}$
 Pressure range from p_t to $p_{\max}$

Only the solidification curve ($x = 11$) is calculated for pressures p for which applies $p_{\max_Ice} < p \leq p_{\max}$.

3. Sublimation Region ($100 \leq x \leq 101$):

The phase fraction x equates to the vapor fraction x in the sublimation region in (kg desublimating steam)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating solid and desublimating steam.

If sublimating solid is to be calculated, the value 100 has to be entered for x . In case of desublimating steam $x = 101$ has to be entered.

If the state point to be calculated is located in the melting region, a value between 100 and 101 must be entered for x .

When calculating a sublimating solid or desublimating steam it is adequate, Concerning pressure and temperature, to put in either the value given for t and $p = -1000$ or the value given for p and $t = -1000$ and the value for x ($x = 100$ or $x = 101$). If p and t and x are entered as given values the program tests whether p and t fulfil the sublimation-pressure-curve.

Sublimation and

desublimation curve Temperatur range from $t_{\min}$ to t_t
 Pressure range from $p_{\min}$ to p_t

Results for wrong input values

Result $VPTXCO2 = -1000$, $H = -1000$ or $v_ptx_CO2 = -1000$ for input values:

Single phase region:

Solid, liquid, overheated steam ($x = -1$):

- at $p < p_{\min}$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ when calculating solid
- at $t < t_{\min}$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ when calculating solid

Two phase regions:

Wet steam region ($0 \leq x \leq 1$):

- at $p = -1000$ and $t < t_t$ or $t > t_c$
- at $t = -1000$ and $p < p_t$ or $p > p_c$
- at $p < p_t$ or $p > p_c$
- at $t < t_t$ or $t > t_c$

Melting region ($10 \leq x \leq 11$):

- at $p = -1000$ and $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$
- at $t = -1000$ and $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$

Sublimation region ($100 \leq x \leq 101$):

- at $p = -1000$ and $t < t_{\min}$ or $t > t_t$
- at $t = -1000$ and $p < p_{\min}$ or $p > p_t$
- at $p < p_{\min}$ or $p > p_t$
- at $t < t_{\min}$ or $t > t_t$

References: [2]

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

Function Name: **w_ptx_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION WPTXCO2(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Subprogram with parameter: **INTEGER*4 FUNCTION C_WPTXCO2(W,P,T,X)**
 for call from the DLL **REAL*8 W,P,T,X**

Input Values

P – Pressure p in bar
T - Temperature t in °C
X - x in kg / kg (Phase fraction, see the following explanations)

Result

WPTXCO2, W or w_ptx_CO2 – Speed of sound w in m/s

Range of Validity (cp. p, t -diagram in chapter 3.1)

Temperature range: from t_t to $t_{\max}$
 Pressure range: from $p_{\min}$ to $p_{\max}$ for liquid and steam

Details on the phase fraction x

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. Calculating solid is not possible.

The two phase regions wet steam region, melting region and sublimation region are calculated automatically by the subprograms. For this purpose the following facts have to be considered (cp. lg p, h -diagram chapter 3.1):

1. Wet Vapor Region ($0 \leq x \leq 1$) :

The phase fraction x equates to the vapor fraction x in the wet steam region in (kg dry saturated steam)/(kg wet steam).

The calculation for x values between 0 and 1 is not possible.

If boiling liquid (boiling curve) is to be calculated, the value 0 has to be entered for x . In case of dry saturated steam (dew curve) $x = 1$ has to be entered.

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 0 or 1 for x must be entered when calculating boiling liquid or dry saturated steam. If p and t and x are entered, the program will consider p and t to represent the vapor pressure curve.

Boiling and dew curve: Temperature range from t_t to t_c
 Pressure range from p_t to p_c

2. Melting Region ($10 \leq x \leq 11$) :

The phase fraction x equates to the liquid fraction x in the melting region in (kg solidifying liquid)/(kg melt), whereas melt is a mixture of melting solid and solidifying liquid.

The calculation for x values of $x = 10$ (melting curve) and between 10 and 11 is not possible.

If solidifying liquid (solidification curve) is to be calculated, the value 11 has to be entered for x .

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 11 for x must be entered when calculating solidifying liquid. If p and t and x are entered as given values, the program tests whether p and t fulfil the melting pressure curve.

Melting curve: Temperature range from t_t to $t_{\max_Ice}$
 Pressure range from p_t to $p_{\max_Ice}$

Solidification curve: Temperature range from t_t to $t_{\max}$
 Pressure range from p_t to $p_{\max}$

3. Sublimation Region ($100 \leq x \leq 101$) :

The phase fraction x equates to the vapor fraction x in the sublimation region in (kg desublimating steam)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating solid and desublimating steam.

The calculation for x values of $x = 100$ (sublimation curve) and between 100 and 101 is not possible. If desublimating steam (desublimation curve) is to be calculated, the value 101 has to be entered for x . Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 101 for x must be entered when calculating desublimating steam. If p and t and x are entered as given values the program tests whether p and t fulfil the sublimation-pressure-curve.

Sublimation and

desublimation curve Temperatur range from $t_{\min}$ to t_t

Pressure range from $p_{\min}$ to p_t

Results for wrong input values

Result **WPTXCO2 = -1000** or **w_ptx_CO2 = -1000** for input values:

Single phase region:

Liquid and overheated steam ($x = -1$):

- at $p < p_{\min}$ or $p > p_{\max}$
- at $t < t_t$ or $t > t_{\max}$

Two phase regions:

Wet steam region ($0 \leq x \leq 1$):

- at $0 < x < 1$, i.e. calculation in the wet steam region not possible!
- at $p = -1000$ and $t < t_t$ or $t > t_{\max}$
- at $t = -1000$ and $p < p_t$ or $p > p_c$
- at $p < p_t$ or $p > p_c$
- at $t < t_t$ or $t > t_c$

Melting region ($10 \leq x \leq 11$):

- at $10 < x < 11$, i.e. calculation on the melting curve and in the melting region not possible!
- at $p = -1000$ and $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$
- at $t = -1000$ and $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_Ice}$ at $x = 10$
- at $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_Ice}$ at $x = 10$

Sublimation region ($100 \leq x \leq 101$):

- at $100 \leq x < 101$, i.e. calculation on the sublimation curve and in the sublimation region not possible!
- at $p = -1000$ and $t < t_{\min}$ or $t > t_t$
- at $t = -1000$ and $p < p_{\min}$ or $p > p_t$
- at $p < p_{\min}$ or $p > p_t$
- at $t < t_{\min}$ or $t > t_t$

References: [2]

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

Function Name: **x_ph_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION XPHCO2(P,H)**
for call from Fortran **REAL*8 P,H**

Subprogram with parameter: **INTEGER*4 FUNCTION C_XPHCO2(T,P,H)**
for call from the DLL **REAL*8 X,P,H**

Input Values

P – Pressure p in bar
H - Specific enthalpy h in kJ/kg

Result

XPHCO2, X or x_ph_CO2 – Vapor fraction x in (kg saturated steam/kg wet steam)

Range of Validity (cp. p, t -diagram in chapter 3.1)

Pressure range: from $p_{\min}$ to $p_{\max}$ for liquid and steam
from $p_{\min}$ to $p_{\max_ice}$ for solid

Enthalpy range: from $h < h_{\max} = h(p_{\min}, t_{\max})$ to $h > h_{\min} = h(p_{\min}, t_{\min})$

Temperature range: from $t_{\min}$ to $t_{\max}$ (resulting from internal calculation of the subprograms)

Details on calculating the two phase regions

The two phase regions are calculated automatically by the subprograms. Using the given values for p and h , the program determines whether the point of state to be calculated is located in the single phase region (solid, liquid or steam) or in one of the two phase regions wet steam region, melting region and sublimation region (cp. lg p, h -diagram in chapter 3.1). When calculating a two phase mixture, x will be calculated. If the state point to be calculated is located in the single-phase region the result is set to $x = -1$.

Results for wrong input values

Result **X_PH_CO2, X = -1** or **x_ph_CO2 = -1** for input values:

If the state point to be calculated is located in the single phase region (cp. lg p, h -diagram in chapter 3.1).

Two phase regions:

Wet steam region ($0 \leq x \leq 1$):

- at $p < p_t$ or $p > p_c$
- at calculation result $t < t_t$ or $t > t_c$

Melting region ($10 \leq x \leq 11$):

- at $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_ice}$ when calculating solid
- at calculation result $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_ice}$ when calculating solid

Sublimation region ($100 \leq x \leq 101$):

- at $p < p_{\min}$ or $p > p_t$
- at calculation result $t < t_{\min}$ or $t > t_t$

References: [2]

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

Function Name: **x_ps_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION XPSCO2(P,S)**
for call from Fortran **REAL*8 P,S**

Subprogram with parameter: **INTEGER*4 FUNCTION C_XPSCO2(X,P,S)**
for call from the DLL **REAL*8 X,P,S**

Input Values

P – Pressure p in bar
S - Specific entropy s in kJ/(kg K)

Result

XPSCO2, X or x_ps_CO2 – Vapor fraction x in (kg saturated steam/kg wet steam)

Range of Validity (cp. p,t -diagram in chapter 3.1)

Pressure range: from $p_{\min}$ to $p_{\max}$ for liquid and steam
from $p_{\min}$ to $p_{\max_ice}$ for solid

Entropy range: from $s < s_{\max} = s(p_{\min}, t_{\max})$ to $s > s_{\min} = s(p_{\min}, t_{\min})$

Temperature range: from $t_{\min}$ to $t_{\max}$ (resulting from internal calculation of the subprograms)

Details on calculating the two phase regions

The two phase regions are calculated automatically by the subprograms. Using the given values for p and s , the program determines whether the point of state to be calculated is located in the single phase region (solid, liquid or steam) or in one of the two phase regions wet steam region, melting region and sublimation region (cp. lg p,h -diagram in chapter 3.1). When calculating a two phase mixture, x will be calculated. If the state point to be calculated is located in the single-phase region the result is set to $x = -1$.

Results for wrong input values

Result **X_PS_CO2, X = -1** or **x_ps_CO2 = -1** for input values:

If the state point to be calculated is located in the single phase region (cp. lg p,h -diagram in chapter 3.1).

Two phase regions:

Wet steam region ($0 \leq x \leq 1$):

- at $p < p_t$ or $p > p_c$
- at calculation result $t < t_t$ or $t > t_c$

Melting region ($10 \leq x \leq 11$):

- at $p < p_t$ or $p > p_{\max}$ or $p > p_{\max_ice}$ when calculating solid
- at calculation result $t < t_t$ or $t > t_{\max}$ or $t > t_{\max_ice}$ when calculating solid

Sublimation region ($100 \leq x \leq 101$):

- at $p < p_{\min}$ or $p > p_t$
- at calculation result $t < t_{\min}$ or $t > t_t$

References: [2]

3.3 Property Functions for Solid Carbon Dioxide (Dry Ice)

#\$K+ **Thermal Diffusivity $a = f(p, t)$**

Function Name: **alCE_pt_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION APICEPTCO2(P,T)**
for call from Fortran **REAL*8 P,T**

Subprogram with parameter: **INTEGER*4 FUNCTION C_APICEPTCO2(A,P,T)**
for call from the DLL **REAL*8 A,P,T**

Input Values

P - Pressure p in bar

T - Temperature t in °C

Result

APICEPTCO2, a or alCE_pt_CO2 – Thermal diffusivity $a = \frac{\lambda * V}{c_p}$ in m²/s

Range of Validity (cp. p, t -diagram in chapter 3.1)

Pressure range: from $p_{\min}$ to $p_{\max_Ice}$

Temperature range: from $t_{\min}$ to $t_{\max_Ice}$

Results for wrong input values

Result **APICEPTCO2 = -1000, A = -1000 or alCE_pt_CO2 = -1000** for input values:

- at $t < t_{\min}$ or $t > t_{\max_Ice}$
- at $p < p_{\min}$ or $p > p_{\max_Ice}$

References: [4], [5]

FUNC_300
\$ $a = f(t)$
K $a = f(t)$
+ SUCH:300

#\$K+ **Specific Isobaric Heat Capacity $c_p = f(p,t)$**

Function Name: **cpICE_pt_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION CPICEPTCO2(P,T)**
 for call from Fortran **REAL*8 P,T**

Subprogram with parameter: **INTEGER*4 FUNCTION C_CPICEPTCO2(CP,P,T)**
 for call from the DLL **REAL*8 CP,P,T**

Input Values

P - Pressure p in bar

T - Temperature t in °C

Result

CPICETCO2, CP or cpICE_t_CO2 – specific isobaric heat capacity c_p in kJ/(kg K)

Range of Validity (cp. p,t -diagram in chapter 3.1)

Pressure range: from $p_{\min}$ to $p_{\max_Ice}$

Temperature range: from $t_{\min}$ to $t_{\max_Ice}$

Results for wrong input values

Result **CPICEPTCO2 = -1000, CP = -1000 or cpICE_pt_CO2 = -1000** for input values:

- at $t < t_{\min}$ or $t > t_{\max_Ice}$
- at $p < p_{\min}$ or $p > p_{\max_Ice}$

References: [4]

FUNC_310
 \$ cpICE = f(t)
 K cpICE = f(t)
 + SUCH:310

\$ K + **Specific Enthalpy $h = f(p, t)$**

Function Name: **hICE_pt_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION HICEPTCO2(P,T)**
 for call from Fortran **REAL*8 P,T**

Subprogram with parameter: **INTEGER*4 FUNCTION C_HICEPTCO2(H,P,T)**
 for call from the DLL **REAL*8 H,P,T**

Input Values

P - Pressure p in bar

T - Temperature t in °C

Result

HICETCO2, H or **hICE_t_CO2** – specific enthalpy h in kJ / kg

Range of Validity (cp. p, t -diagram in chapter 3.1)

Pressure range: from $p_{\min}$ to $p_{\max_Ice}$

Temperature range: from $t_{\min}$ to $t_{\max_Ice}$

Results for wrong input values

Result **HICEPTCO2 = -1000, H = -1000** or **hICE_pt_CO2 = -1000** for input values:

- at $t < t_{\min}$ or $t > t_{\max_Ice}$
- at $p < p_{\min}$ or $p > p_{\max_Ice}$

References: [4]

FUNC_320
 \$ hICE = f(t)
 K hICE = f(t)
 + SUCH:320

#\$K+ **Thermal Conductivity $\lambda = f(t)$**

Function Name: **lambdaICE_t_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION LAMICETCO2(T)**
for call from Fortran **REAL*8 T**

Subprogram with parameter: **INTEGER*4 FUNCTION C_LAMICETCO2(LAM,T)**
for call from the DLL **REAL*8 LAM,T**

Input Values

T - Temperature t in °C

Result

LAMICETCO2, LAM or **lambdaICE_t_CO2** – Thermal conductivity λ in W/m K

Range of Validity (cp. p,t -diagram in chapter 3.1)

Temperature range: from $t_{\min}$ to $t_{\max_Ice}$

Results for wrong input values

Result **LAMICETCO2 = -1000, LAM = -1000** or **lambdaICE_t_CO2 = -1000** for input values:

- at $t < t_{\min}$ or $t > t_{\max_Ice}$

References: [5]

FUNC_330
\$ lambdaICE = f(t)
K lambdaICE = f(t)
+ SUCH:330

#\$K+ Density $\rho = f(p,t)$

Function Name: **rhoICE_pt_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION RHOICEPTCO2(P,T)**
for call from Fortran **REAL*8 P,T**

Subprogram with parameter: **INTEGER*4 FUNCTION C_RHOICEPTCO2(RHO,P,T)**
for call from the DLL **REAL*8 RHO,P,T**

Input Values

P - Pressure p in bar

T - Temperature t in °C

Result

RHOICEPTCO2, RHO or rhoICE_pt_CO2 - Density ρ in kg/m³

Range of Validity (cp. p,t -diagram in chapter 3.1)

Pressure range: from $p_{\min}$ to $p_{\max_Ice}$

Temperature range: from $t_{\min}$ to $t_{\max_Ice}$

Results for wrong input values

Result **RHOICEPTCO2 = -1000, RHO = -1000 or rhoICE_pt_CO2 = -1000** for input values:

- at $t < t_{\min}$ or $t > t_{\max_Ice}$

- at $p < p_{\min}$ or $p > p_{\max_Ice}$

References: [4]

FUNC_340
\$ rhoICE = f(t)
K rhoICE = f(t)
+ SUCH:340

#\$K+ **Specific Entropy $s = f(p,t)$**

Function Name: **sICE_pt_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION SICEPTCO2(P,T)**
for call from Fortran **REAL*8 P,T**

Subprogram with parameter: **INTEGER*4 FUNCTION C_SICEPTCO2(S,P,T)**
for call from the DLL **REAL*8 S,P,T**

Input Values

P - Pressure p in bar

T - Temperature t in °C

Result

SICEPTCO2, S or **sICE_pt_CO2** – Specific Entropy s in kJ/(kg K)

Range of Validity (cp. p,t -diagram in chapter 3.1)

Pressure range: from $p_{\min}$ to $p_{\max_Ice}$

Temperature range: from $t_{\min}$ to $t_{\max_Ice}$

Results for wrong input values

Result **SICEPTCO2 = -1000, S = -1000** or **sICE_pt_CO2 = -1000** for input values:

- at $t < t_{\min}$ or $t > t_{\max_Ice}$
- at $p < p_{\min}$ or $p > p_{\max_Ice}$

References: [4]

FUNC_350
\$ sICE = f(t)
K sICE = f(t)
+ SUCH:350

#\$K+ **Specific Volume $v = f(p,t)$**

Function Name: **VICE_pt_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION VICEPTCO2(P,T)**
for call from Fortran **REAL*8 P,T**

Subprogram with parameter: **INTEGER*4 FUNCTION C_VICETCO2(V,P,T)**
for call from the DLL **REAL*8 V,P,T**

Input Values

P - Pressure p in bar

T - Temperature t in °C

Result

VICEPTCO2, V or **VICE_pt_CO2** – specific volume v in m³/kg

Range of Validity (cp. p,t -diagram in chapter 3.1)

Pressure range: from $p_{\min}$ to $p_{\max_Ice}$

Temperature range: from $t_{\min}$ to $t_{\max_Ice}$

Results for wrong input values

Result **VICEPTCO2 = -1000, V = -1000** or **VICE_pt_CO2 = -1000** for input values:

- at $t < t_{\min}$ or $t > t_{\max_Ice}$
- at $p < p_{\min}$ or $p > p_{\max_Ice}$

References: [4]

FUNC_360
\$ VICE = f(t)
K VICE = f(t)
+ SUCH:360

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

Function Name: **tICE_ph_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION TICEPHCO2(P,H)**
 for call from Fortran **REAL*8 P,H**

Subprogram with parameter: **INTEGER*4 FUNCTION C_TICEPHCO2(T,P,H)**
 for call from the DLL **REAL*8 T,P,H**

Input Values

P - Pressure p in bar

H – Specific enthalpy h in kJ/kg

Result

TICEPHCO2, T or tICE_ph_CO2 - Temperature in °C

Range of Validity (cp. p,t -diagram in chapter 3.1)

Enthalpy range: from $h > h_{\min} = h(t_{\min})$ to $h < h_{\max_Ice} = h(t_{\max_Ice})$

Pressure range: from $p_{\min}$ to $p_{\max_Ice}$

Temperature range: for results from $t_{\min}$ to $t_{\max_Ice}$

Results for wrong input values

Result **TICEPHCO2 = -1000, T = -1000 or tICE_ph_CO2 = -1000** for input values:

- at $h < h_{\min} = h(t_{\min})$ or $h > h_{\max_Ice} = h(t_{\max_Ice})$ or

- at $p < p_{\min}$ or $p > p_{\max_Ice}$

References: [4]

FUNC_370

\$ tICE = f(h)

K tICE = f(h)

+ SUCH:370

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

Function Name: **tICE_ps_CO2**

Subprogram with value of the function: **REAL*8 FUNCTION TICEPSCO2(P,S)**
for call from Fortran **REAL*8 P,S**

Subprogram with parameter: **INTEGER*4 FUNCTION C_TICEPSCO2(T,P,S)**
for call from the DLL **REAL*8 T,P,S**

Input Value

P - Pressure p in bar

S – Specific Entropy in kJ/(kg K)

Result

TICEPSCO2, T or tICE_ps_CO2 - Temperature in °C

Range of Validity (cp. p,t -diagram in chapter 3.1)

Entropy range: from $s > s_{\min} = s(t_{\min})$ to $s < s_{\max_Ice} = s(t_{\max_Ice})$

Pressure range: from $p_{\min}$ to $p_{\max_Ice}$

Temperature range: for results from $t_{\min}$ to $t_{\max_Ice}$

Results for wrong input values

Result **TICEPSCO2 = -1000, T = -1000 or tICE_ps_CO2 = -1000** for input values:

- at $s < s_{\min} = s(t_{\min})$ or $s > s_{\max_Ice} = s(t_{\max_Ice})$

- at $p < p_{\min}$ or $p > p_{\max_Ice}$

References: [4]

FUNC_380
\$ tICE = f(s)
K tICE = f(s)
+ SUCH:380



4. 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:
- CO₂ - Span and Wagner O₂ - Schmidt and Wagner
H₂O - IAPWS-95 Ar - Tegeler et al.
N₂ - Span et al.
- and of the ideal gases:
- SO₂, 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 (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

- Model: Ideal mixture of the ideal gases:
- | | | | |
|-----------------|------------------|-----------------|------------|
| Ar | NO | He | Propylene |
| Ne | H ₂ O | F ₂ | Propane |
| N ₂ | SO ₂ | NH ₃ | Iso-Butane |
| O ₂ | H ₂ | Methane | n-Butane |
| CO | H ₂ S | Ethane | Benzene |
| CO ₂ | OH | Ethylene | Methanol |
| Air | | | |

- Consideration of:
- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

- Consideration of:
- Dissociation from the VDI Guideline 4670

Humid Air

Library ASHRAE LibHuAirProp

Model: Virial Equation from ASHRAE Report RP-1485 for real mixture of the real fluids:

- Dry air
- Steam

- Consideration of:
- Enhancement of the partial saturation pressure of water vapor at elevated total pressures
- www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bückner and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bückner and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

Helmholtz energy equation for the mixing term (also useable for calculating Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

- | | |
|---|---------------------|
| C ₂ H ₆ O ₂ | Ethylene glycol |
| C ₃ H ₈ O ₂ | Propylene glycol |
| C ₂ H ₅ OH | Ethyl alcohol |
| CH ₃ OH | Methyl alcohol |
| C ₃ H ₈ O ₃ | Glycerol |
| K ₂ CO ₃ | Potassium carbonate |
| CaCl ₂ | Calcium chloride |
| MgCl ₂ | Magnesium chloride |
| NaCl | Sodium chloride |
| C ₂ H ₃ KO ₂ | Potassium acetate |

Formulation of the International Institute of Refrigeration (1997)

Ethanol**Library LibC2H5OH**

Formulation of Schroeder
(2012)

Methanol**Library LibCH3OH**

Formulation of
de Reuck and Craven (1993)

Propane**Library LibPropane**

Formulation of
Lemmon et al. (2009)

Siloxanes as ORC Working Fluids

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

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Nitrogen**Library LibN2**

Formulation of
Span et al. (2000)

Hydrogen**Library LibH2**

Formulation of
Leachman et al. (2009)

Helium**Library LibHe**

Formulation of Arp et al. (1998)

Hydrocarbons

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

Isopentane C_5H_{12} **Library LibC5H12_ISO**

Neopentane C_5H_{12} **Library LibC5H12_NEO**

Isohexane C_6H_{14} **Library LibC6H14**

Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

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

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

Hydrogen sulfide **H₂S** **Library LibH2S**

Dinitrogen monoxide **N₂O** **Library LibN2O**

Sulfur dioxide **SO₂** **Library LibSO2**

Acetone **C₃H₆O** **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

For more information please contact:

Zittau/Goerlitz University of Applied Sciences
Department of Technical Thermodynamics
Professor Hans-Joachim Kretzschmar
Dr. Ines Stoecker

Theodor-Koerner-Allee 16
02763 Zittau, Germany

Internet: www.thermodynamics-zittau.de
E-mail: hj.kretzschmar@hszg.de
Phone: +49-3583-61-1846
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

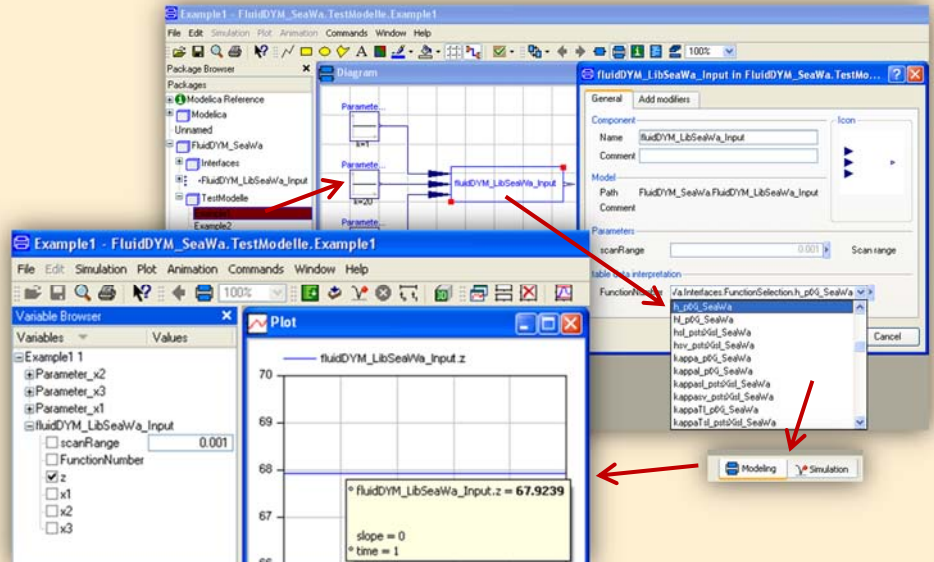
Backward Functions

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

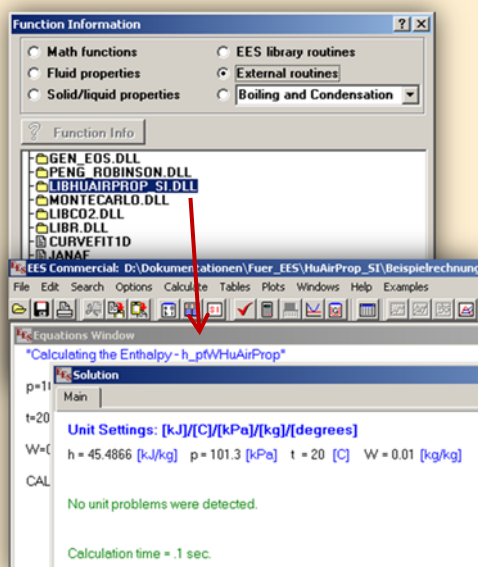
Thermodynamic Derivatives

- Partial derivatives can be calculated.

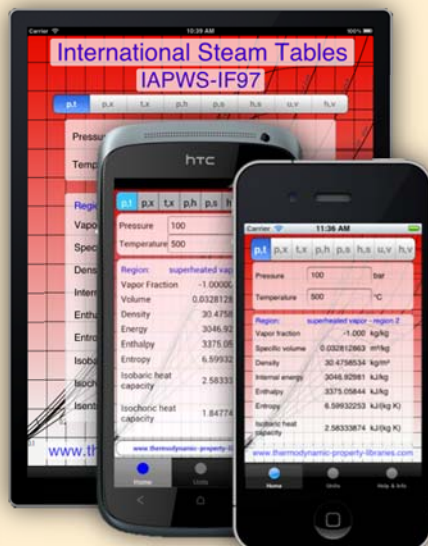
^a Not all of these property functions are available in all property libraries.



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

Zittau's Fluid Property Calculator

Fluid:

Function:

Unit System:

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

Pressure p: bar

Temperature t: °C

Vapor fraction x: kg/kg

Calculate / Recalculate

Result:

Specific enthalpy h = 3097.38 kJ/kg

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

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

PDF with the description

© Zittau/Goerlitz University of Applied Sciences
Faculty of Mechanical Engineering
Department of Technical Thermodynamics
Prof. Hans-Joachim Kretzschmar
Dr. Ines Stoecker
Programmer: Joachim Posselt

Tel.: +49-3583-61-1846 or -1881
Fax: +49-3583-61-1845
E-mail: info@thermodynamics-zittau.de
www.thermodynamics-zittau.de
www.thermodynamic-property-libraries.com
www.international-steam-tables.com
www.thermodynamic-formelsammlung.de

Property Software for Pocket Calculators

FluidCasio



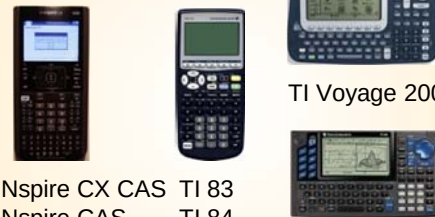
fx 9750 G II CFX 9850 fx-GG20 CFX 9860 G Graph 85 ALGEBRA FX 2.0

FluidHP



HP 48 HP 49

FluidTI



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

For more information please contact:

Zittau/Goerlitz University of Applied Sciences
Department of Technical Thermodynamics
Professor Hans-Joachim Kretzschmar
Dr. Ines Stoecker
Theodor-Koerner-Allee 16
02763 Zittau, Germany

E-mail: hj.kretzschmar@hs-zigr.de
Internet: www.thermodynamics-zittau.de
Phone: +49-3583-61-1846
Fax: +49-3583-61-1846

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.

5. References

- [1] Kretzschmar, H.-J.:
Zur Aufbereitung und Darbietung thermophysikalischer Stoffdaten für die Energietechnik.
Habilitation, TU Dresden, Fakultät Maschinenwesen (1990)
- [2] Span, R.; Wagner W.:
A New Equation of State for Carbon Dioxide Covering the Fluid Region from the Triple-Point Temperature to 1100 K at Pressures up to 800 MPa.
J. Phys. Chem. Ref. Data, 25, (1996) Nr. 6, S. 1506-1596
- [3] Vesovic, V.; Wakeham, W. A.; Olchowky, G. A.; Sengers, J. V.; Watson, J. T. R.; Millat, J.:
The Transport Properties of Carbon Dioxide.
J. Phys. Chem. Ref. Data, 19, (1990) Nr. 3, S. 763-808
- [4] Jäger, A.; Span, R.:
Equation of State for Solid Carbon Dioxide Based on the Gibbs Free Energy.
J. Chem. Eng. Data 57 (2012), 590-597
- [5] Kuprianoff, J.:
Die feste Kohlensäure (Trockeneis) – Herstellung und Verwendung
Ferdinand Enke Verlag Stuttgart, 1953

6. Satisfied Customers

Date: 04/2014

The following companies and institutions use the property libraries

- FluidEXL^{Graphics} for Excel[®]
- FluidLAB for MATLAB[®]
- FluidMAT for Mathcad[®]
- FluidEES for Engineering Equation Solver[®] EES
- FluidDYM for Dymola[®] (Modelica) and SimulationX[®]
- FluidVIEW for LabVIEW[®]:

2014

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

2013

TRANTER-GmbH, Artern	12/2013
SATAKE, Shanghai, China	12/2013
VOITH, Kunshan, China	12/2013
ULT, Löbau	12/2013
MAN, Copenhagen, Dänemark	11/2013
DREWAG, Dresden	11/2013
Haarslev Industries, Herlev, Dänemark	11/2013
STEAG, Herne	11/2013, 12/2013
Ingersoll-Rand, Oberhausen	11/2013
Wilhelm-Büchner HS, Darmstadt	10/2013
IAV, Chemnitz	10/2013
Technical University of Regensburg	10/2013
PD-Energy, Bitterfeld	09/2013
Thermofin, Heinsdorfergrund	09/2013
SHI, New Jersey, USA	09/2013
M&M Turbinentechnik, Bielefeld	08/2013
BEG-BHV, Bremerhaven	08/2013
TIG-Group, Husum	08/2013
COMPAREX, Leipzig for RWE Essen	08/2013, 11/2013 12/2013
University of Budapest, Hungary	08/2013
Siemens, Frankenthal	08/2013, 10/2013 11/2013
VGB, Essen	07/2013, 11/2013
Brunner Energieberatung, Zurich, Switzerland	07/2013
Technical University of Deggendorf	07/2013
University of Maryland, USA	07/2013, 08/2013
University of Princeton, USA	07/2013
NIST, Boulder, USA	06/2013
IGUS GmbH, Dresden	06/2013
BHR Bilfinger, Essen	06/2013
SÜDSALZ, Bad Friedrichshall	06/2013, 12/2013
Technician School of Berlin	05/2013
KIER, Gajeong-ro, Südkorea	05/2013

Schwing/Stetter GmbH, Memmingen	05/2013
Vattenfall, Berlin	05/2013
AUTARK, Kleinmachnow	05/2013
STEAG, Zwingenberg	05/2013
Hochtief, Düsseldorf	05/2013
University of Stuttgart	04/2013
Technical University -Bundeswehr, Munich	04/2013
Rerum Cognitio Forschungszentrum, Frankfurt	04/2013
Kältetechnik Dresden + Bremen, Alfhausen	04/2013
University Auckland, New Zealand	04/2013
MASDAR Institut, Abu Dhabi, United Arab Emirates	03/2013
Simpelkamp, Dresden	02/2013
VEO, Eisenhüttenstadt	02/2013
ENTEC, Auerbach	02/2013
Caterpillar, Kiel	02/2013
Technical University of Wismar	02/2013
Technical University of Dusseldorf	02/2013
ILK, Dresden	01/2013, 08/2013
Fichtner IT, Stuttgart	01/2013, 11/2013
Schnepf Ingenieurbüro, Nagold	01/2013
Schütz Engineering, Wadgassen	01/2013
Endress & Hauser, Reinach, Switzerland	01/2013
Oschatz GmbH, Essen	01/2013
frischli Milchwerke, Rehburg-Loccum	01/2013

2012

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

Rerum Cognitio Forschungszentrum, Frankfurt	09/2012
Pöyry Deutschland GmbH, Dresden	08/2012
Extracciones, Guatemala	08/2012
RWE, Essen	08/2012
Weghaus Consulting Engineers, Wuerzburg	08/2012
GKS, Schweinfurt	07/2012
COMPAREX, Leipzig for RWE Essen	07/2012
GEA, Nobitz	07/2012
Meyer Werft, Papenburg	07/2012
STEAG, Herne	07/2012
GRS, Cologne	06/2012
Fichtner IT Consult, Chennai, India	06/2012
Siemens, Freiburg	06/2012
Nikon Research of America, Belmont, USA	06/2012
Niederrhein University of Applied Sciences, Krefeld	06/2012
STEAG, Zwingenberg	06/2012
Mainova, Frankfurt on Main via Fichtner IT Consult	05/2012
Endress & Hauser	05/2012
PEU, Espenheim	05/2012
Luzern University of Applied Sciences, Switzerland	05/2012
BASF, Ludwigshafen (general license) via Fichtner IT Consult	05/2012
SPX Balcke-Dürr, Ratingen	05/2012, 07/2012
Gruber-Schmidt, Wien, Austria	04/2012
Vattenfall, Berlin	04/2012
ALSTOM, Baden	04/2012
SKW, Piesteritz	04/2012
TERA Ingegneria, Trento, Italy	04/2012
Siemens, Erlangen	04/2012, 05/2012
LAWI Power, Dresden	04/2012
Stadtwerke Leipzig	04/2012
SEITZ, Wetzikon, Switzerland	03/2012, 07/2012
M & M, Bielefeld	03/2012
Sennheiser, Wedemark	03/2012

SPG, Montreuil Cedex, France	02/2012
German Destillation, Sprendlingen	02/2012
Lopez, Munguia, Spain	02/2012
Endress & Hauser, Hannover	02/2012
Palo Alto Research Center, USA	02/2012
WIPAK, Walsrode	02/2012
Freudenberg, Weinheim	01/2012
Fichtner, Stuttgart	01/2012
airinotec, Bayreuth	01/2012, 07/2012
University Auckland, New Zealand	01/2012
VPC, Vetschau	01/2012
Franken Guss, Kitzingen	01/2012

2011

XRG-Simulation, Hamburg	12/2011
Smurfit Kappa PPT, AX Roermond, Netherlands	12/2011
AWTEC, Zurich, Switzerland	12/2011
eins-energie, Bad Elster	12/2011
BeNow, Rodenbach	11/2011
Luzern University of Applied Sciences, Switzerland	11/2011
GMVA, Oberhausen	11/2011
CCI, Karlsruhe	10/2011
W.-Büchner University of Applied Sciences, Pfungstadt	10/2011
PLANAIR, La Sagne, Switzerland	10/2011
LAWI, Dresden	10/2011
Lopez, Munguia, Spain	10/2011
University of KwaZulu-Natal, Westville, South Africa	10/2011
Voith, Heidenheim	09/2011
SpgBe Montreal, Canada	09/2011
SPG TECH, Montreuil Cedex, France	09/2011
Voith, Heidenheim-Mergelstetten	09/2011
MTU Aero Engines, Munich	08/2011
MIBRAG, Zeitz	08/2011
RWE, Essen	07/2011
Fels, Elingerode	07/2011

Weihenstephan University of Applied Sciences	07/2011, 09/2011 10/2011
Forschungszentrum Juelich	07/2011
RWTH Aachen University	07/2011, 08/2011
INNEO Solutions, Ellwangen	06/2011
Caliqua, Basel, Switzerland	06/2011
Technical University of Freiberg	06/2011
Fichtner IT Consulting, Stuttgart	05/2011, 06/2011, 08/2011
Salzgitter Flachstahl, Salzgitter	05/2011
Helbling Beratung & Bauplanung, Zurich, Switzerland	05/2011
INEOS, Cologne	04/2011
Enseleit Consulting Engineers, Siebigerode	04/2011
Witt Consulting Engineers, Stade	03/2011
Helbling, Zurich, Switzerland	03/2011
MAN Diesel, Copenhagen, Denmark	03/2011
AGO, Kulmbach	03/2011
University of Duisburg	03/2011, 06/2011
CCP, Marburg	03/2011
BASF, Ludwigshafen	02/2011
ALSTOM Power, Baden, Switzerland	02/2011
Universität der Bundeswehr, Munich	02/2011
Calorifer, Elgg, Switzerland	01/2011
STRABAG, Vienna, Austria	01/2011
TUEV Sued, Munich	01/2011
ILK Dresden	01/2011
Technical University of Dresden	01/2011, 05/2011 06/2011, 08/2011

2010

Umweltinstitut Neumarkt	12/2010
YIT Austria, Vienna, Austria	12/2010
MCI Innsbruck, Austria	12/2010
University of Stuttgart	12/2010
HS Cooler, Wittenburg	12/2010
Visteon, Novi Jicin, Czech Republic	12/2010
CompuWave, Brunntal	12/2010

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

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

2009

ALSTOM Power, Baden, Schweiz	01/2009, 03/2009 05/2009
Nordostschweizerische Kraftwerke AG, Doettingen, Switzerland	02/2009
RWE, Neurath	02/2009
Brandenburg University of Technology, Cottbus	02/2009
Hamburg University of Applied Sciences	02/2009
Kehrein, Moers	03/2009
EPP Software, Marburg	03/2009
Bernd Münstermann, Telgte	03/2009
Suedzucker, Zeitz	03/2009
CPP, Marburg	03/2009
Gelsenkirchen University of Applied Sciences	04/2009
Regensburg University of Applied Sciences	05/2009
Gatley & Associates, Atlanta, USA	05/2009

BOSCH, Stuttgart	06/2009, 07/2009
Dr. Nickolay, Consulting Engineers, Gommersheim	06/2009
Ferrostal Power, Saarlouis	06/2009
BHR Bilfinger, Essen	06/2009
Intraserv, Wiesbaden	06/2009
Lausitz University of Applied Sciences, Senftenberg	06/2009
Nuernberg University of Applied Sciences	06/2009
Technical University of Berlin	06/2009
Fraunhofer Institut UMSICHT, Oberhausen	07/2009
Bischoff, Aurich	07/2009
Fichtner IT Consulting, Stuttgart	07/2009
Techsoft, Linz, Austria	08/2009
DLR, Stuttgart	08/2009
Wienstrom, Vienna, Austria	08/2009
RWTH Aachen University	09/2009
Vattenfall, Hamburg	10/2009
AIC, Chemnitz	10/2009
Midiplan, Bietigheim-Bissingen	11/2009
Institute of Air Handling and Refrigeration ILK, Dresden	11/2009
FZD, Rossendorf	11/2009
Techgroup, Ratingen	11/2009
Robert Sack, Heidelberg	11/2009
EC, Heidelberg	11/2009
MCI, Innsbruck, Austria	12/2009
Saacke, Bremen	12/2009
ENERKO, Aldenhoven	12/2009
2008	
Pink, Langenwang	01/2008
Fischer-Uhrig, Berlin	01/2008
University of Karlsruhe	01/2008
MAAG, Kuesnacht, Switzerland	02/2008
M&M Turbine Technology, Bielefeld	02/2008
Lentjes, Ratingen	03/2008
Siemens Power Generation, Goerlitz	04/2008
Evonik, Zwingenberg (general EBSILON program license)	04/2008

WEBASTO, Neubrandenburg	04/2008
CFC Solutions, Munich	04/2008
RWE IT, Essen	04/2008
Rerum Cognitio, Zwickau	04/2008, 05/2008
ARUP, Berlin	05/2008
Research Center, Karlsruhe	07/2008
AWECO, Neukirch	07/2008
Technical University of Dresden, Professorship of Building Services	07/2008
Technical University of Cottbus, Chair in Power Plant Engineering	07/2008, 10/2008
Ingersoll-Rand, Unicov, Czech Republic	08/2008
Technip Benelux BV, Zoetermeer, Netherlands	08/2008
Fennovoima Oy, Helsinki, Finland	08/2008
Fichtner Consulting & IT, Stuttgart	09/2008
PEU, Espenhain	09/2008
Poyry, Dresden	09/2008
WINGAS, Kassel	09/2008
TUEV Sued, Dresden	10/2008
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	10/2008, 11/2008
AWTEC, Zurich, Switzerland	11/2008
Siemens Power Generation, Erlangen	12/2008

2007

Audi, Ingolstadt	02/2007
ANO Abfallbehandlung Nord, Bremen	02/2007
TUEV NORD SysTec, Hamburg	02/2007
VER, Dresden	02/2007
Technical University of Dresden, Chair in Jet Propulsion Systems	02/2007
Redacom, Nidau, Switzerland	02/2007
Universität der Bundeswehr, Munich	02/2007
Maxxtec, Sinsheim	03/2007
University of Rostock, Chair in Technical Thermodynamics	03/2007
AGO, Kulmbach	03/2007
University of Stuttgart, Chair in Aviation Propulsions	03/2007
Siemens Power Generation, Duisburg	03/2007

ENTHAL Haustechnik, Rees	05/2007
AWECO, Neukirch	05/2007
ALSTOM, Rugby, Great Britain	06/2007
SAAS, Possendorf	06/2007
Grenzbach BSH, Bad Hersfeld	06/2007
Reichel Engineering, Haan	06/2007
Technical University of Cottbus, Chair in Power Plant Engineering	06/2007
Voith Paper Air Systems, Bayreuth	06/2007
Egger Holzwerkstoffe, Wismar	06/2007
Tissue Europe Technologie, Mannheim	06/2007
Dometic, Siegen	07/2007
RWTH Aachen University, Institute for Electrophysics	09/2007
National Energy Technology Laboratory, Pittsburg, USA	10/2007
Energieversorgung Halle	10/2007
AL-KO, Jettingen	10/2007
Grenzbach BSH, Bad Hersfeld	10/2007
Wiesbaden University of Applied Sciences, Department of Engineering Sciences	10/2007
Endress+Hauser Messtechnik, Hannover	11/2007
Munich University of Applied Sciences, Department of Mechanical Engineering	11/2007
Rerum Cognitio, Zwickau	12/2007
Siemens Power Generation, Erlangen	11/2007
University of Rostock, Chair in Technical Thermodynamics	11/2007, 12/2007

2006

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

Technical University of Munich, Chair in Apparatus and Plant Engineering	02/2006
Energietechnik Leipzig (company license),	02/2006
Siemens Power Generation, Erlangen	02/2006, 03/2006
RWE Power, Essen	03/2006
WAETAS, Pobershau	04/2006
Siemens Power Generation, Goerlitz	04/2006
Technical University of Braunschweig, Department of Thermodynamics	04/2006
EnviCon & Plant Engineering, Nuremberg	04/2006
Brassel Engineering, Dresden	05/2006
University of Halle-Merseburg, Department of USET Merseburg incorporated society	05/2006
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	05/2006
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	05/2006
Suedzucker, Ochsenfurt	06/2006
M&M Turbine Technology, Bielefeld	06/2006
Feistel Engineering, Volkach	07/2006
ThyssenKrupp Marine Systems, Kiel	07/2006
Caliqua, Basel, Switzerland (company license)	09/2006
Atlas-Stord, Rodovre, Denmark	09/2006
Konstanz University of Applied Sciences, Course of Studies Construction and Development	10/2006
Siemens Power Generation, Duisburg	10/2006
Hannover University of Applied Sciences, Department of Mechanical Engineering	10/2006
Siemens Power Generation, Berlin	11/2006
Zikesch Armaturentechnik, Essen	11/2006
Wismar University of Applied Sciences, Seafaring Department	11/2006
BASF, Schwarzheide	12/2006
Enertech Energie und Technik, Radebeul	12/2006

2005

TUEV Nord, Hannover	01/2005
J.H.K Plant Engineering and Service, Bremerhaven	01/2005
Electrowatt-EKONO, Zurich, Switzerland	01/2005

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

2004

Vattenfall Europe (group license)	01/2004
TUEV Nord, Hamburg	01/2004
University of Stuttgart, Institute of Thermodynamics and Heat Engineering	02/2004
MAN B&W Diesel A/S, Copenhagen, Denmark	02/2004
Siemens AG Power Generation, Erlangen	02/2004

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

2003

Paper Factory, Utzenstorf, Switzerland	01/2003
MAB Plant Engineering, Vienna, Austria	01/2003
Wulff Energy Systems, Husum	01/2003
Technip Benelux BV, Zoetermeer, Netherlands	01/2003
ALSTOM Power, Baden, Switzerland	01/2003, 07/2003
VER, Dresden	02/2003
Rietschle Energieplaner, Winterthur, Switzerland	02/2003
DLR, Leupholdhausen	04/2003

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

2002

Hamilton Medical AG, Rhaezuens, Switzerland	01/2002
Bochum University of Applied Sciences, Department of Thermo- and Fluid Dynamics	01/2002
SAAS, Possendorf/Dresden	02/2002
Siemens, Karlsruhe (general license for the WinIS information system)	02/2002
FZR Forschungszentrum, Rossendorf/Dresden	03/2002

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

2001

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

Siemens, Karlsruhe (general license for the WinIS information system)	08/2001
Neusiedler AG, Ulmerfeld, Austria	09/2001
h s energieanlagen, Freising	09/2001
Electrowatt-EKONO, Zurich, Switzerland	09/2001
IPM Zittau/Goerlitz University of Applied Sciences (general license)	10/2001
eta Energieberatung, Pfaffenhofen	11/2001
ALSTOM Power Baden, Switzerland	12/2001
VEAG, Berlin (group license)	12/2001

2000

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

1999

Bayernwerk, Munich	01/1999
DREWAG, Dresden (company license)	02/1999
KEMA IEV, Dresden	03/1999

Regensburg University of Applied Sciences	04/1999
Fichtner Consulting & IT, Stuttgart (company licenses and distribution)	07/1999
Technical University of Cottbus, Chair in Power Plant Engineering	07/1999
Technical University of Graz, Department of Thermal Engineering, Austria	11/1999
Ostendorf Engineering, Gummersbach	12/1999

1998

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

1997

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