

# Property Library for Carbon Dioxide

## **FluidEXL** *Graphics* with **LibCO2** for Excel<sup>®</sup>

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# **Software for the Calculation of the Properties of Carbon Dioxide Including DLL and Add-In for Excel® FluidEXL *Graphics* LibCO2**

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## 0 Package Contents

### 0.1 Zip files for 64-bit Office®

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

CD\_FluidEXL\_Graphics\_Eng\_LibCO2\_x64.zip

including the following folders and files:

\FLUFT\

\Formulation97\

FluidEXL\_Graphics\_LibCO2\_Docu\_Eng.pdf

FluidEXL\_Graphics\_Eng.xla

LC.dll

LibCO2.dll

LibCO2.chm.

### 0.2 Zip files for 32-bit Office®

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

CD\_FluidEXL\_Graphics\_Eng\_LibCO2.zip

including the following folders and files:

\FLUFT\

\Formulation97\

FluidEXL\_Graphics\_LibCO2\_Docu\_Eng.pdf

FluidEXL\_Graphics\_Eng.xla

LC.dll

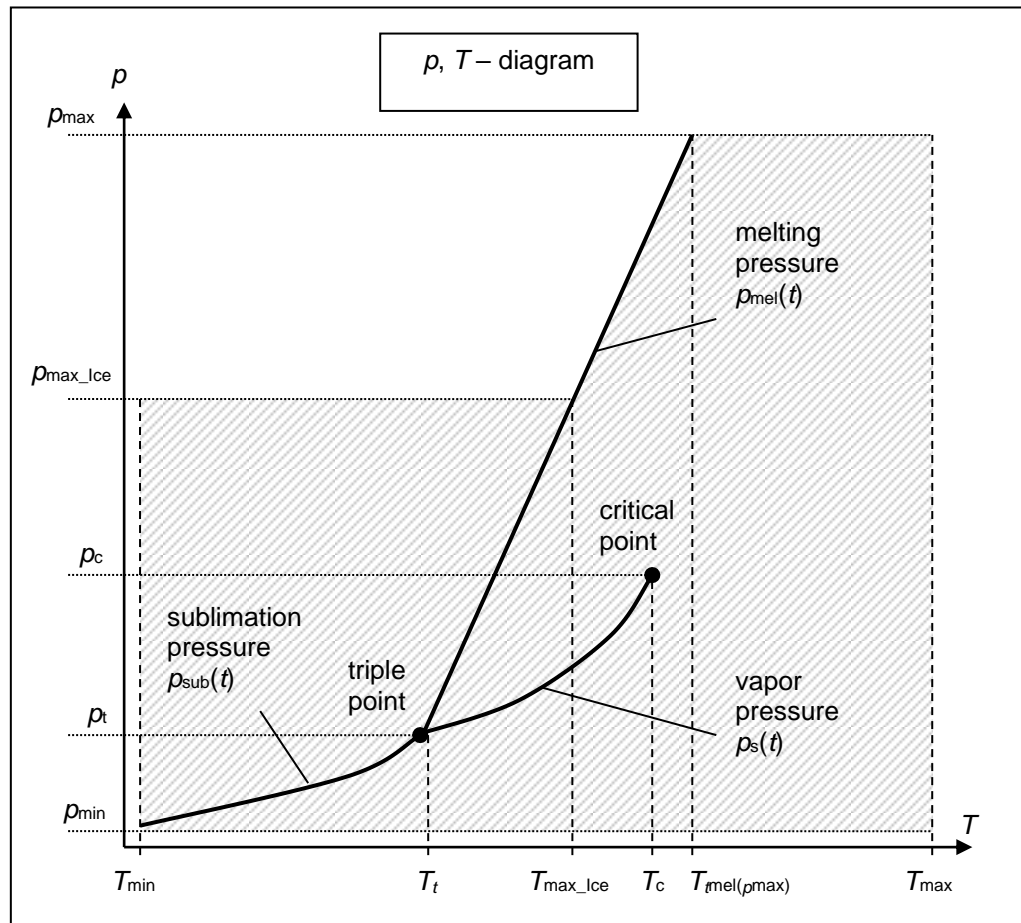
LibCO2.dll

LibCO2.chm.

# 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	$T_{\min}(t_{\min})$	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	$T_{mel}(p_{\max})(t_{mel}(p_{\max}))$	327.671 K (54.521 °C)
Minimum pressure	$p_{\min} = p_{\text{sub}}(T_{\min})$	$2.9081875815 \cdot 10^{-10}$ 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	$p_{\max\_Ice}$	1000 bar

### General Property Functions

Functional Dependence	Function Name	Call from Fortran program	Property or Function	Unit of the Result
$a = f(p, t, x)$	a_ptx_CO2	APTXXCO2(P,T,X)	Thermal diffusivity	m <sup>2</sup> /s
$c_p = f(p, t, x)$	cp_ptx_CO2	CPPTXXCO2(P,T,X)	Specific isobaric heat capacity	kJ/(kg K)
$c_v = f(p, t, x)$	cv_ptx_CO2	CVPTXXCO2(P,T,X)	Specific isochoric heat capacity	kJ/(kg K)
$\eta = f(p, t, x)$	eta_ptx_CO2	ETAPTXCO2(P,T,X)	Dynamic viscosity	Pa s
$h = f(p, t, x)$	h_ptx_CO2	HPTXXCO2(P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p, t, x)$	kappa_ptx_CO2	KAPTXCO2(P,T,X)	Isentropic exponent	-
$\lambda = f(p, t, x)$	lambda_ptx_CO2	LAMPTCO2(P,T,X)	Thermal conductivity	W/(m K)
$\nu = f(p, t, x)$	ny_ptx_CO2	NYPTXXCO2(P,T,X)	Kinematic viscosity	m <sup>2</sup> /s
$p_{\text{mel}} = f(t)$	pmel_t_CO2	PMELCO2(T)	Melting pressure from temperature	bar
$p_{\text{sub}} = f(t)$	psub_t_CO2	PSUBCO2(T)	Sublimation pressure from temperature	bar
$p_s = f(t)$	ps_t_CO2	PSTCO2(T)	Vapor pressure from temperature	bar
$Pr = f(p, t, x)$	Pr_ptx_CO2	PRPTXXCO2(P,T,X)	Prandtl-Number	-
$\rho = f(p, t, x)$	rho_ptx_CO2	ROPTXXCO2(P,T,X)	Density	kg/ m <sup>3</sup>
$s = f(p, t, x)$	s_ptx_CO2	SPTXXCO2(P,T,X)	Specific entropy	kJ/(kg K)
$t = f(p, h)$	t_ph_CO2	TPHCO2(P,H)	Backward function: Temperature from pressure and enthalpy	°C

Functional Dependence	Function Name	Call from Fortran program	Property or Function	Unit of the Result
$t = f(p, s)$	t_ps_CO2	TPSCO2(P,S)	Backward function: Temperature from pressure and entropy	°C
$t_{\text{mel}} = f(p)$	tmel_p_CO2	TMELCO2(P)	Melting temperature from pressure	°C
$t_{\text{sub}} = f(p)$	tsub_p_CO2	TSUBCO2(P)	Sublimation temperature from pressure	°C
$t_s = f(p)$	ts_p_CO2	TSPCO2(P)	Saturation temperature from pressure	°C
$v = f(p, t, x)$	v_ptx_CO2	VPTXCO2(P,T,X)	Specific volume	m³/kg
$w = f(p, t, x)$	w_ptx_CO2	WPTXCO2(P,T,X)	Isentropic speed of sound	m/s
$x = f(p, h)$	x_ph_CO2	XPHCO2(P,H)	Backward function: Phase fraction from pressure and enthalpy	kg/kg
$x = f(p, s)$	x_ps_CO2	XPSCO2(P,S)	Backward function: Phase fraction from pressure and entropy	kg/kg
$z = f(p, t, x)$	z_ptx_CO2	ZPTXCO2(P,T,X)	Compression factor	-

### 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)

Functional Dependence	Function Name	Call from Fortran program	Call from the DLL LibCO2 as Parameter	Property or Function	Unit of the Result
$\rho = f(p, t)$	rhoICE_pt_CO2	RHOICETCO2(P,T)	C_RHOICEPTCO2 (RHO, P, T)	Density	kg/ m <sup>3</sup>
$s = f(p, t)$	sICE_pt_CO2	SICETCO2(P,T)	C_SICEPTCO2 (S, P, T)	Specific entropy	kJ/ (kg K)
$v = f(p, t)$	vICE_pt_CO2	VICETCO2(P,T)	C_VICEPTCO2 (V, P, T)	Specific volume	m <sup>3</sup> /kg
$t = f(p, h)$	tlICE_ph_CO2	TICEHCO2(P,H)	C_TICEPHCO2 (T, P, H)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p, s)$	tlICE_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  $T_t = 216.592$  K ( $t_t = -56.558$  °C) to  $T_c = 304.1282$  K ( $t_t = 30.9782$  °C)

Pressure ranges from  $p_t = 5.179618369088$  bar to  $p_c = 73.773$  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  $-1000$ .

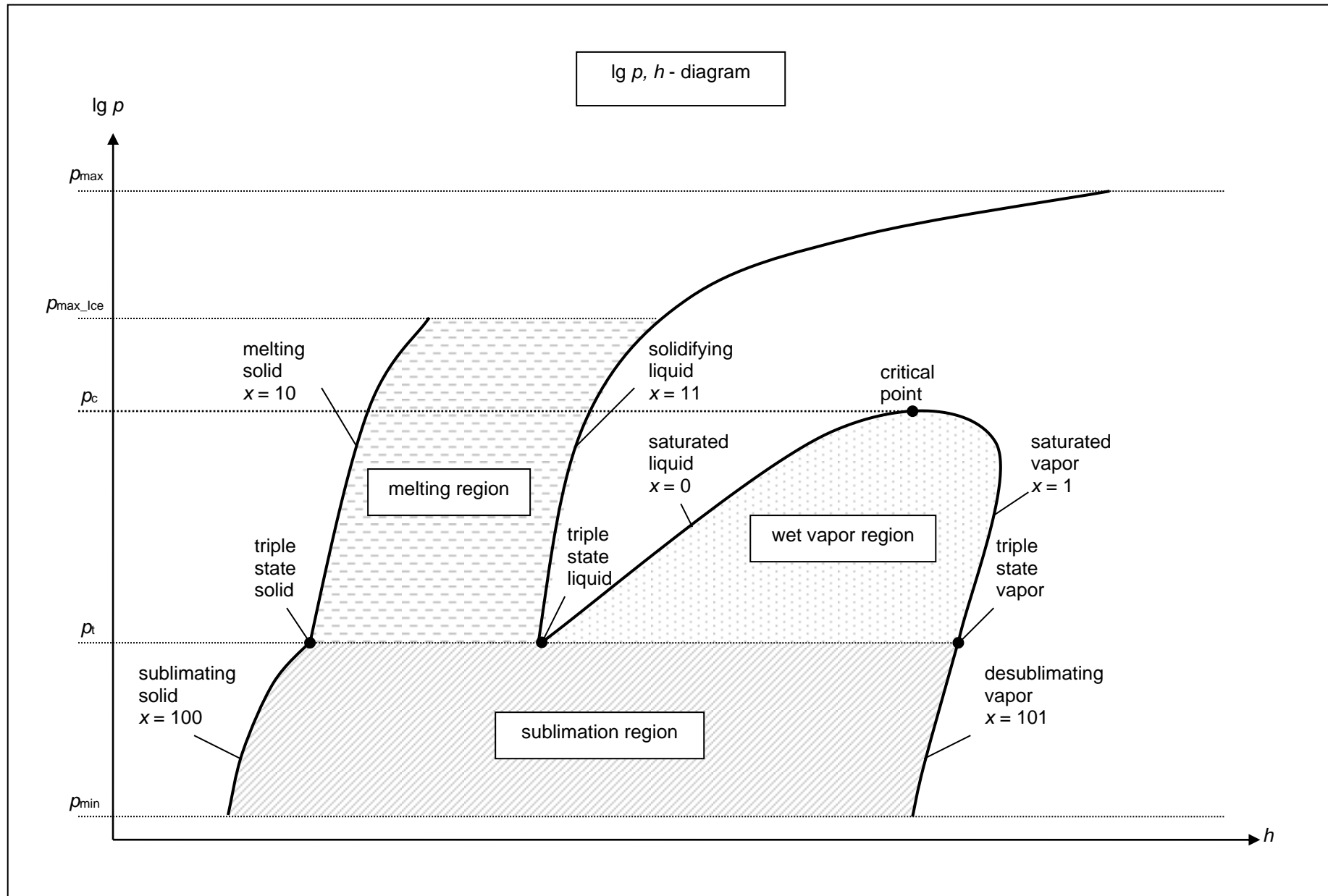
When calculating sublimation powder,  $x$  takes a value between 100 and 101 ( $x = 100$  for sublimating solid,  $x = 101$  for desublimating vapor). In this case, the backward functions result in the appropriate value between 100 and 101 for  $x$ .

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 Water and Steam from the LibCO2 property program library.

### 2.1 Installing FluidEXL *Graphics*

Complete the following steps for initial installation of FluidEXL *Graphics*.

Before you begin, it is best to uninstall any older version of FluidEXL *Graphics*.

The installation routine for 32-bit and 64-bit versions of Excel is similar. The following instructions are valid for both versions.

After you have downloaded and extracted the zip-file:

CD\_FluidEXL\_Graphics\_LibCO2\_x64\_Eng.zip (for 64 bit version)

or

CD\_FluidEXL\_Graphics\_LibCO2\_Eng.zip" (for 32 bit version).

you will see the folder

\CD\_FluidEXL\_Graphics\_LibCO2\_x64\_Eng\ (for 64 bit version)

or

\CD\_FluidEXL\_Graphics\_LibCO2\_Eng\ (for 32 bit version)

in your Windows Explorer, Total Commander etc.

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

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

\FLUFT\  
 \Formulation97\  
 FluidEXL\_Graphics\_Eng.xla  
 FluidEXL\_Graphics\_LibCO2\_Docu\_Eng  
 LC.dll  
 LibCO2.dll  
 LibCO2.chm  
 Reg\_.reg

Now, please copy the following folders and files

\FLUFT\  
 \Formulation97\  
 FluidEXL\_Graphics\_Eng.xla  
 LibCO2.dll  
 LibCO2.chm  
 LC.dll

into the folder

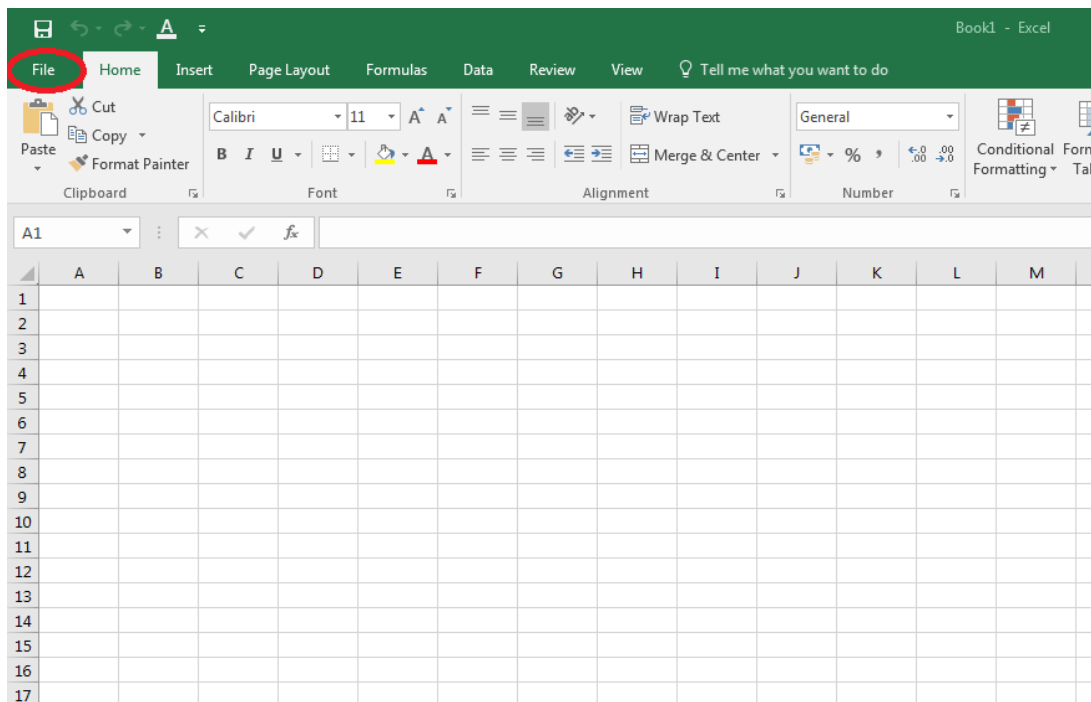
C:\Users\[your name]\AppData\Roaming\Microsoft\AddIns\  
 where [your name] is your name in the Windows system.

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

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

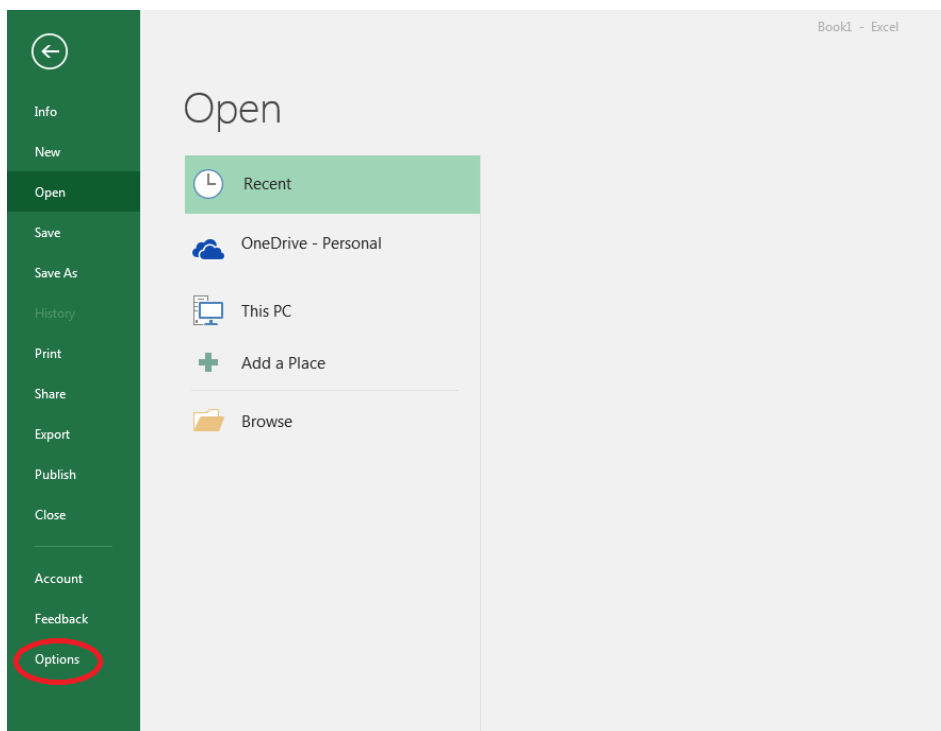
After installation in Windows®, FluidEXL *Graphics* must be registered in Excel® as an Add-In. To do this, start Excel® and carry out the following steps:

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



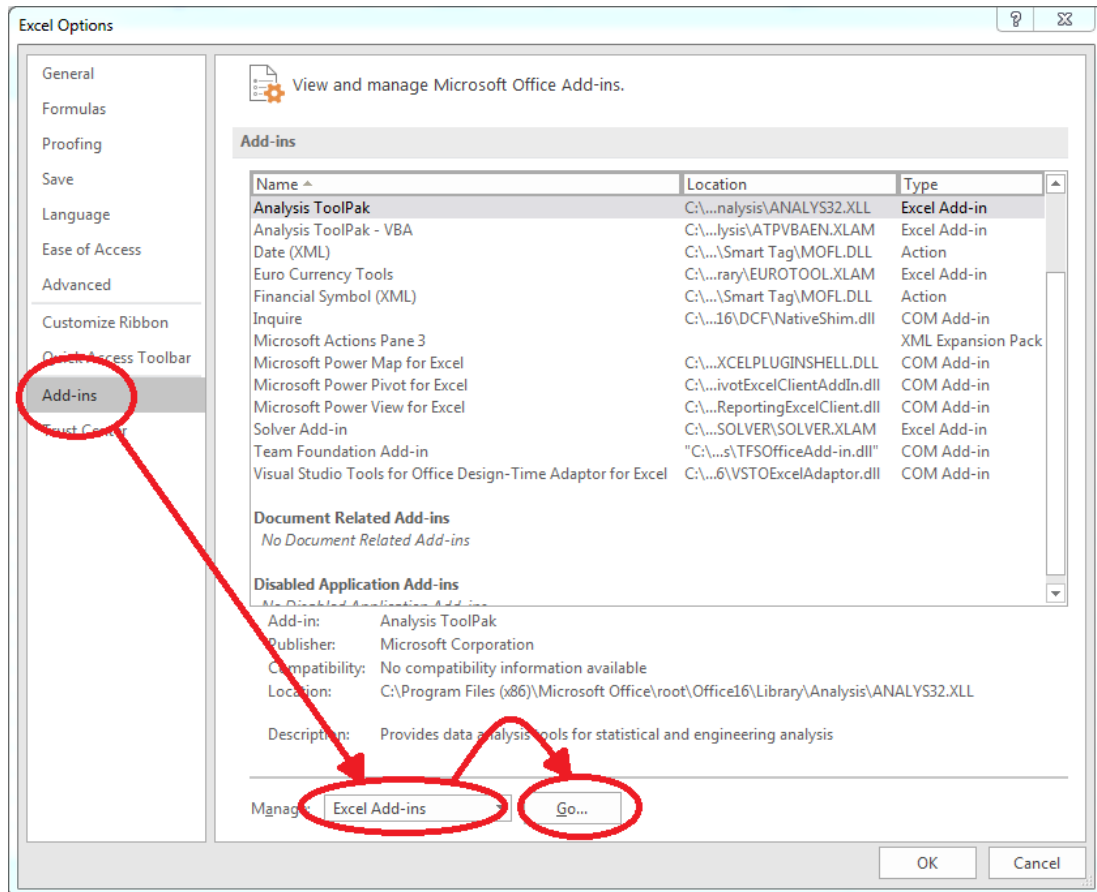
**Figure 2.1:** Registering FluidEXL *Graphics* as Add-In in Excel® 2016

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



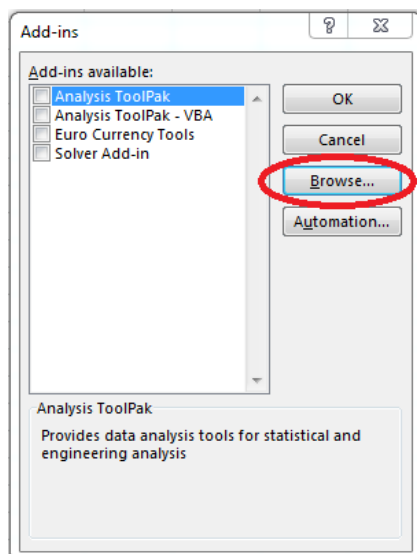
**Figure 2.2:** Registering FluidEXL *Graphics* as Add-In in Excel® 2016

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



**Figure 2.3:** Dialog window "Excel Options"

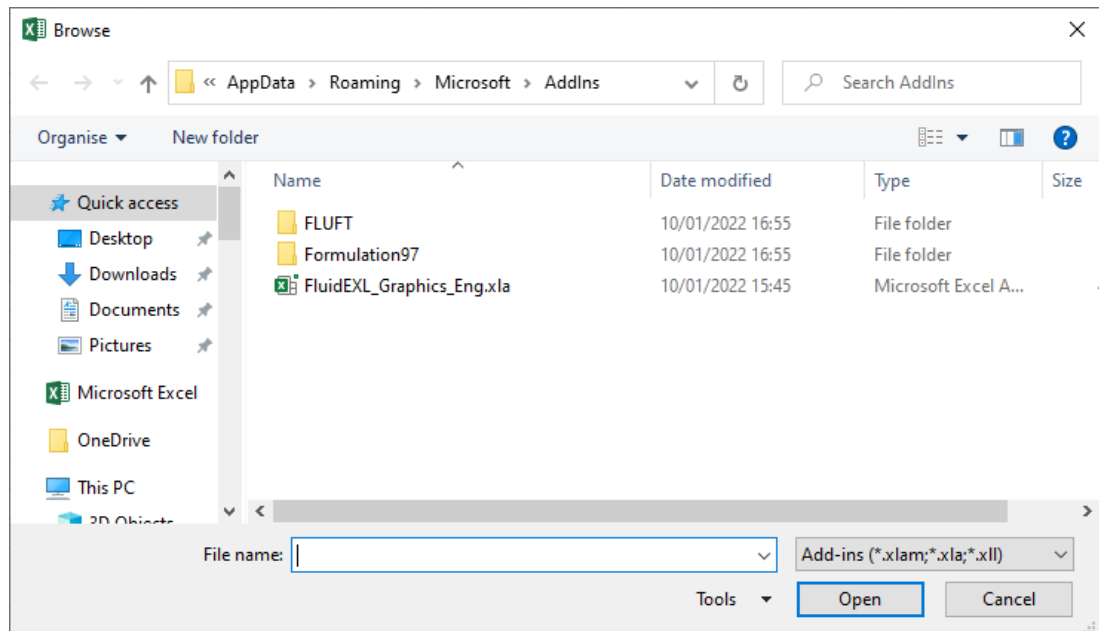
- Select "Excel Add-ins" next to "Manage:" in the lower area of the menu
- Then click the "Go..." button
- Click "Browse" in the following window (Fig. 2.4)



**Figure 2.4:** Dialog window "Add-ins"

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

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



**Figure 2.5:** "Browse"-Window

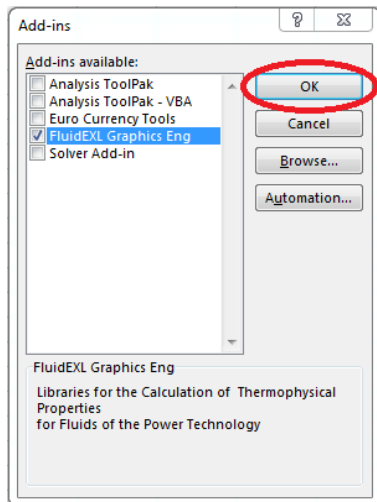
Please copy this path and paste it into your file manager.

Now, please copy the following directories and files:

\FLUFT\  
 \Formulation97\  
 LC.dll  
 FluidEXL\_Graphics\_Eng.xla  
 LibCO2.dll  
 LibCO2.chm

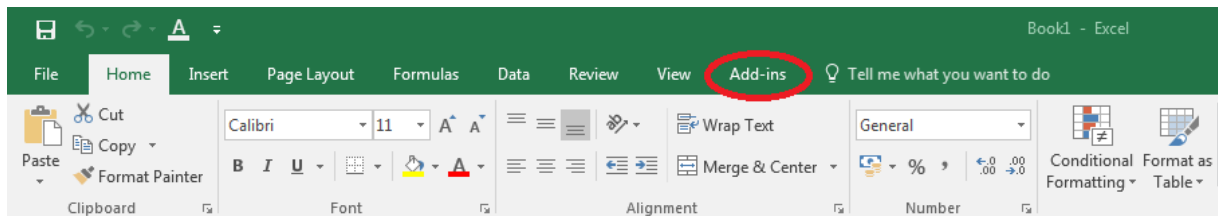
from the delivered CD-folder into this folder.

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



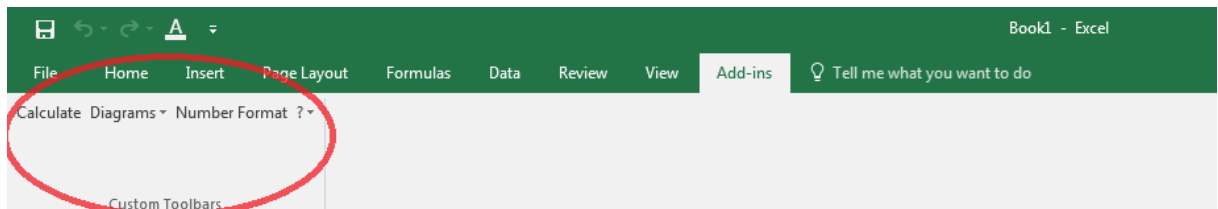
**Figure 2.6:** Dialog window "Add-Ins"

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



**Figure 2.7:** Menu item "Add-Ins"

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



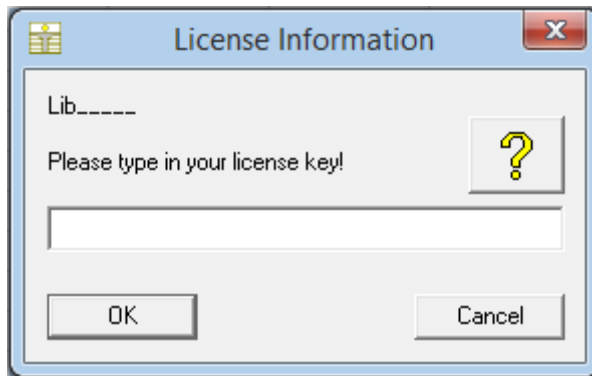
**Figure 2.8:** FluidEXL *Graphics* menu bar

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

An example calculation of "LibCO2" DLL library property functions can be found in chapter 2.4.

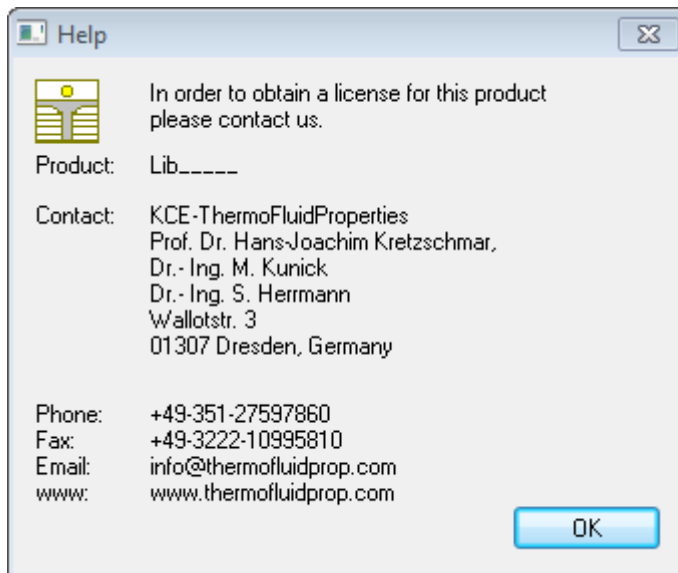
### 2.3 Licensing the LibCO2 Property LibCO2rary

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



**Figure 2.12:** "License Information" window

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



**Figure 2.13:** "Help" window

If you do not enter a valid license it is still possible to start Excel® by clicking "Cancel" twice. In this case, the 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 FluidEXLGraphics 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.chm

in the installation folder of FluidEXLGraphics (the standard being)

C:\Program Files\FluidEXL\_Graphics\_Eng  
using an appropriate program such as Explorer® or Norton Commander.

**Note:**

*The product name "LibCO2\_ \_ \_ \_" in Figure 2.12 and 2.13 stands for the LibCO2rary you are installing. In this case it is the LibCO2 library.*

## 2.4 Example calculation

Now we will calculate, step by step, the specific enthalpy  $h$  as a function of pressure  $p$ , temperature  $t$ , and vapor fraction  $x$ , using FluidEXL *Graphics*. 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:  $t = t_{\text{mel}} \dots 826.85$  °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

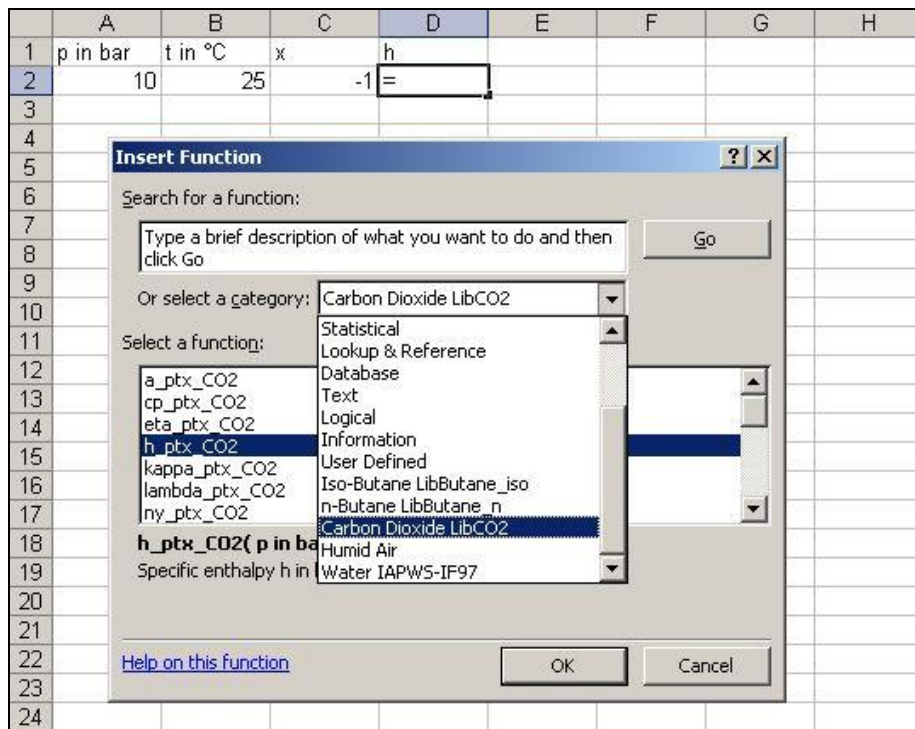
When calculating wet steam, a value between 0 and 1 ( $x = 0$  for boiling liquid,  $x = 1$  for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for  $x$ . It is adequate to enter either the given value for  $t$  and  $p = -1000$ , 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  $-1000$ .

(CO<sub>2</sub> 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.

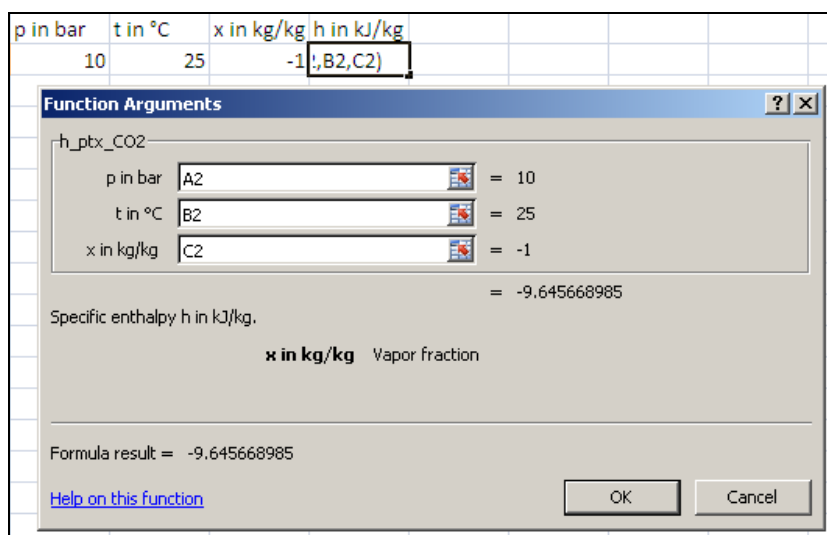
- Click the cell in which the enthalpy  $h$  calculated in kJ/kg is to be displayed.  
⇒ e.g. Click the cell D2.
- Click "Calculate" in the FluidEXL *Graphics* menu bar.  
Now, the "Insert Function" window appears (see Figure 2.9).





**Figure 2.9:** 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 2.10 appears.



**Figure 2.10:** 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.

## 2.5 The FluidEXL *Graphics* Help System

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

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

- Click "Calculate" in the FluidEXL *Graphics* menu bar.
- Click on the "LibCO2" library under "Or select a category:" in the "Insert Function" window which will appear.
- Click the "Help on this function" button in the lower left-hand edge of the "Insert Function" window.

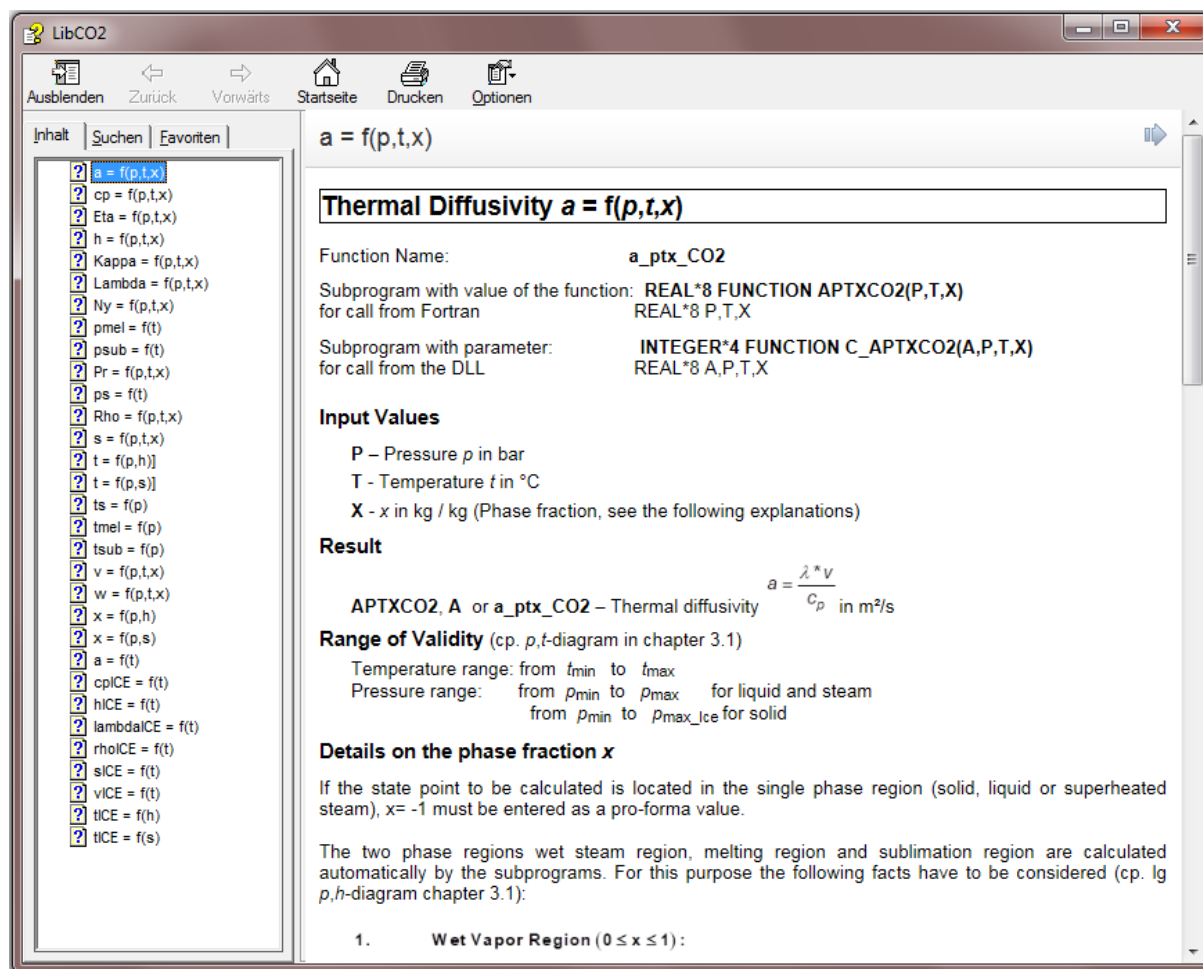


Figure 2.11: Help Window

If the LibCO2.chm function help cannot be found, you will be redirected to a Microsoft® help website by your standard browser. In this case, the LibCO2.chm file has to be copied into the folder of FluidEXL *Graphics*, in the standard case

C:\Program Files\FluidEXL\_Graphics\_Eng

to use the help system.

## 2.6 Removing FluidEXLGraphics

### 2.6.1 Removing LibCO2 Library

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

LibCO2.dll

LibCO2.chm

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

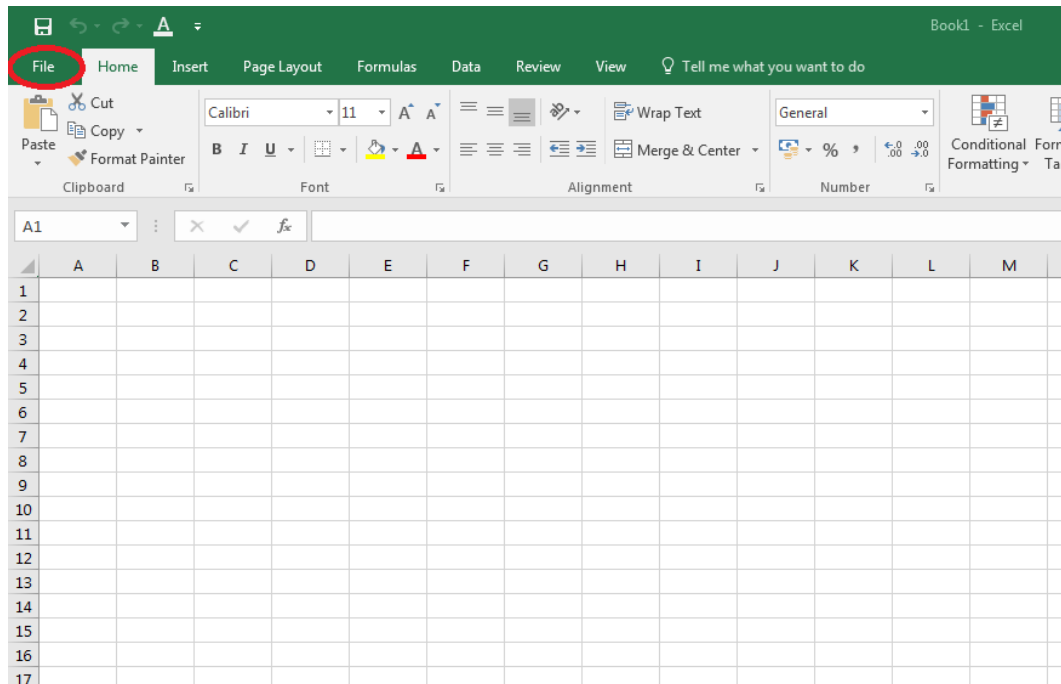
C:\Program Files\FluidEXL\_Graphics\_Eng

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

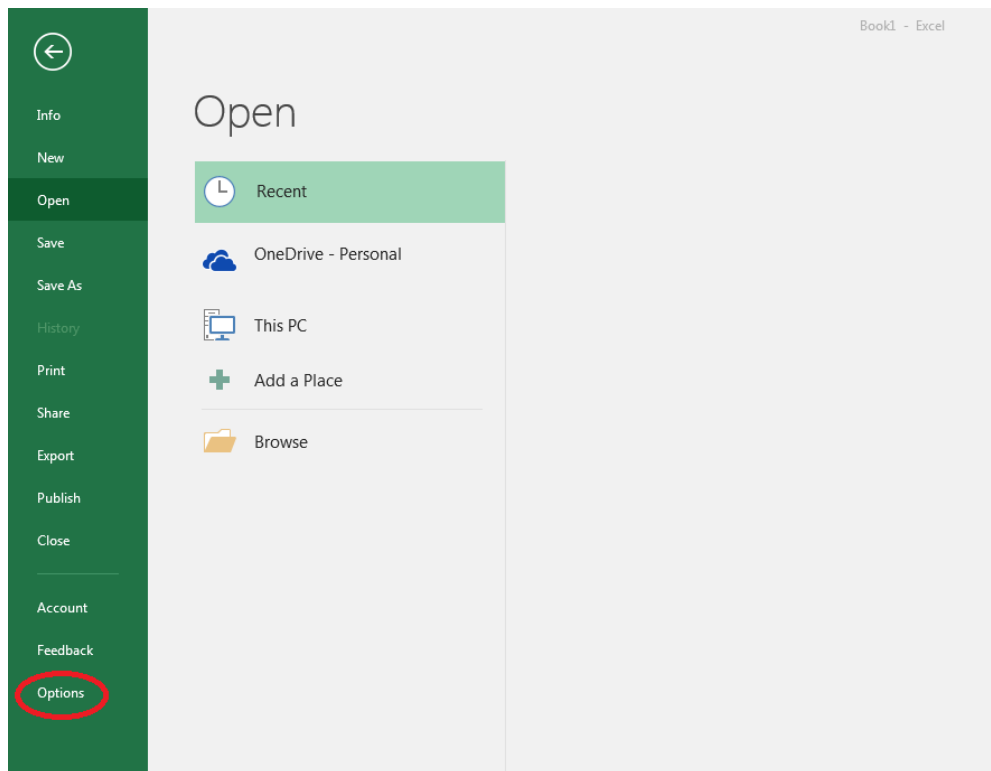
### 2.6.2 Unregistering and uninstalling FluidEXL *Graphics* as Add-In in versions of Excel® from 2007 onwards (for earlier versions see 2.6.3)

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

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

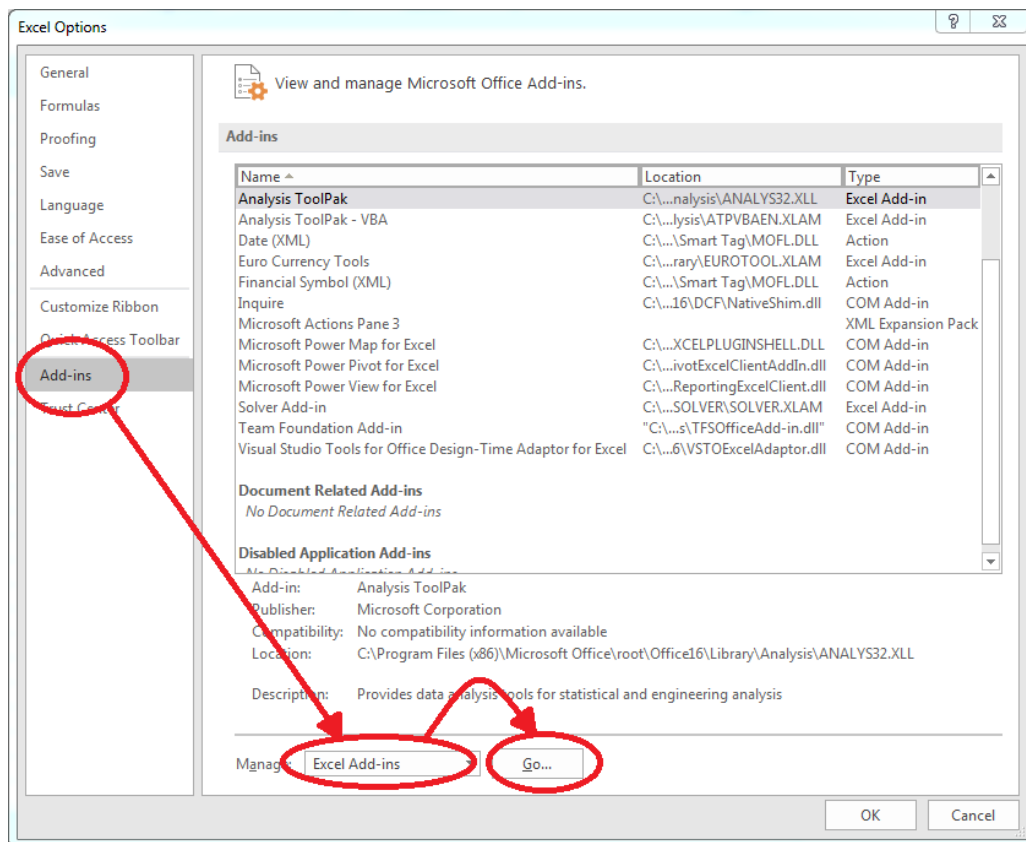


**Figure 2.12:** Unregistering FluidEXL *Graphics* as Add-In in Excel® 2016



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

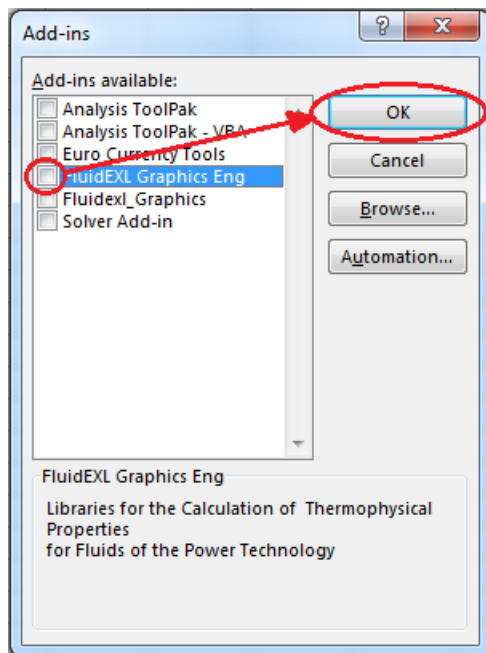
- Click on "Add-Ins" in the next menu (Figure 2.14)



**Figure 2.14:** Dialog window "Add-Ins"

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

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



**Figure 2.15:** Dialog window "Add-Ins"

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

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

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

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

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

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

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

Now FluidEXL<sup>Graphics</sup> has been completely removed from your computer.

### 2.6.3 Unregistering and uninstalling FluidEXL<sup>Graphics</sup> as Add-In in Excel®, versions 2003 or earlier

To remove FluidEXL<sup>Graphics</sup> completely, proceed as follows: First the registration of FluidEXL\_Graphics\_Eng.xla has to be cancelled in Excel®.

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

"FluidEXL Graphics Eng"

in the window that appears and click the "OK" button. The additional menu bar of FluidEXL<sup>Graphics</sup> disappears from the upper part of the Excel® window. Afterwards, we

recommend closing Excel®.

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

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

"FluidEXL Graphics Eng"

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

Within the next step delete the files

LibCO2.dll

LibCO2.chm

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

C:\Program Files\FuildEXL\_Graphics\_Eng

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

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

"FluidEXL Graphics Eng"

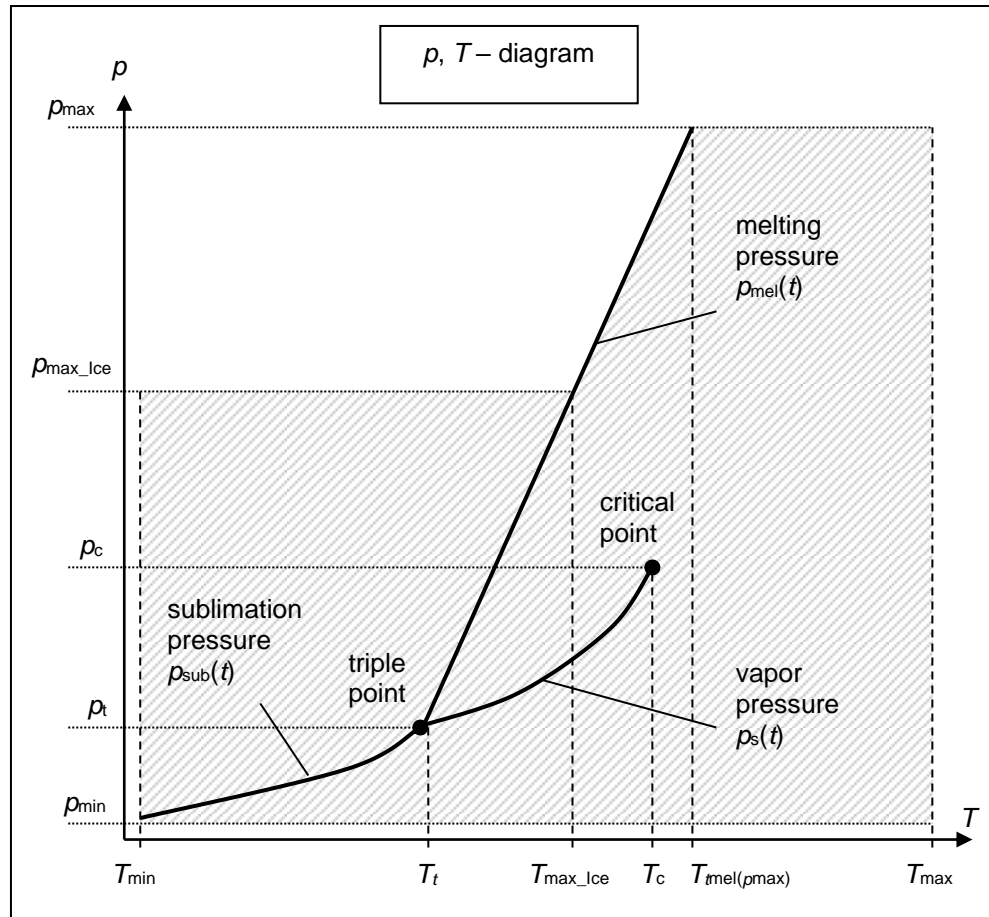
by clicking on it and click the "Add/Remove..." button. In the following dialog box, click "Automatic" and then "Next >". Click "Finish" in the "Perform Uninstall" window. Answer the question whether all shared components shall be removed with "Yes to All". Finally, close the "Add/Remove Programs" and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

Now FluidEXL *Graphics* has been removed.



### 3. Program Documentation

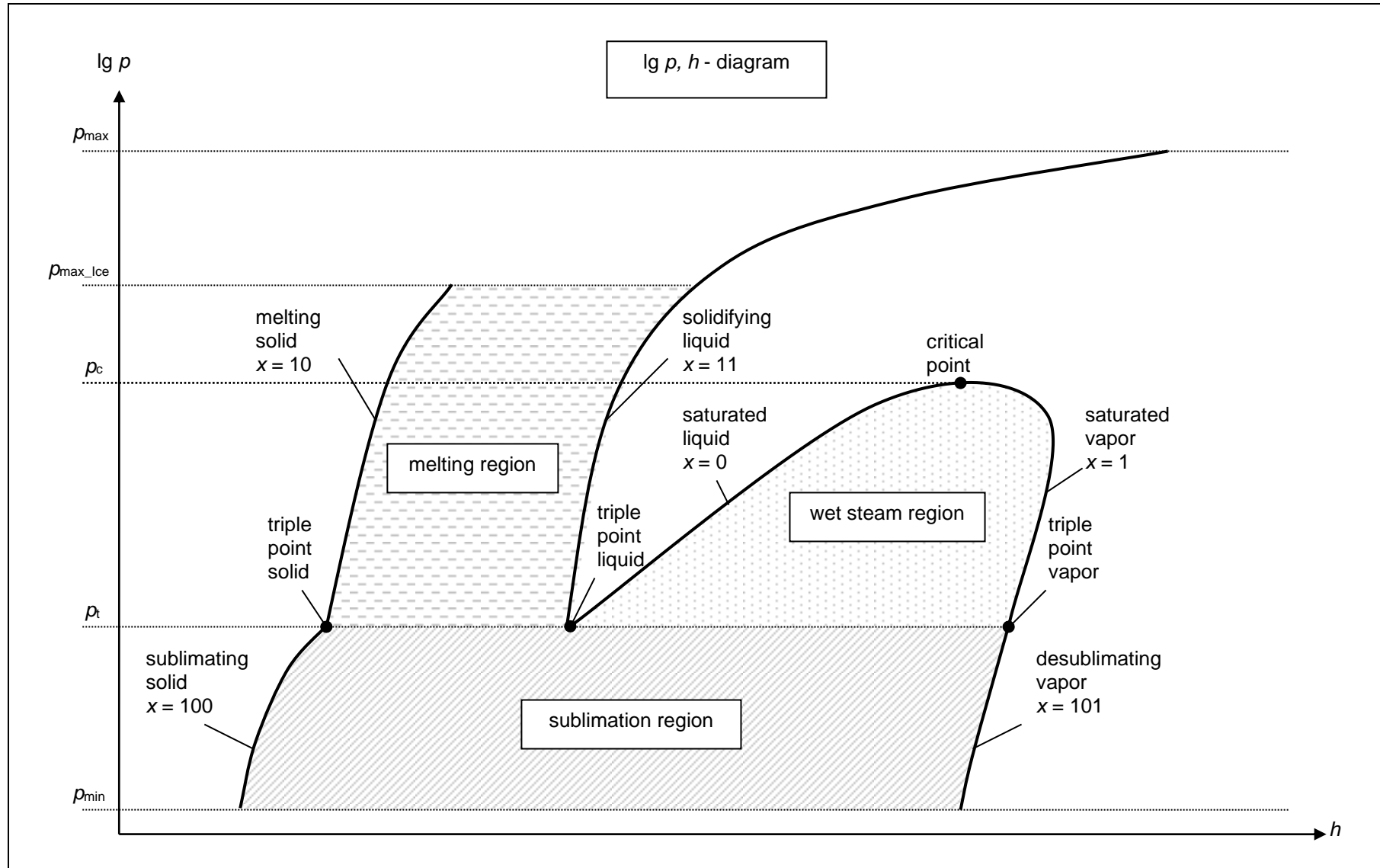
#### 3.1 Ranges of Validity



#### Reference State:

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

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



## 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**

#### 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 m<sup>2</sup>/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  $t_b$  to  $t_c$   
 Pressure range from  $p_b$  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  $t_b$  to  $t_{\max\_Ice}$   
 Pressure range from  $p_b$  to  $p_{\max\_Ice}$

Solidification curve: Temperature range from  $t_b$  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  $t$  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 **APT\_XCO2 = -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  $t > t_{\max}$  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  $p > p_{\max}$
- at  $t < t_t$  or  $t > t_{\max}$

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: [1], [2]

## 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**

### 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: [1]

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

Function Name: **cv\_ptx\_CO2**

Subprogram with value of the function: **REAL\*8 FUNCTION CVPTXCO2(P,T,X)**  
 for call from Fortran **REAL\*8 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

**CVPTXCO2, CV** or **cv\_ptx\_CO2** - specific isochoric heat capacity  $c_p$  in kJ/(kg K)

### Range of Validity (cv. $p, t$ -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 (cv.  $lg\ p, h$ -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 **CVPTXCO2 = -1000, CV = -1000** or **cv\_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: [1]



## 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**

### Input Values

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

### Result

**ETAPTCO2, ETA** or **eta\_ptx\_CO2** – dynamic viscosity  $\eta$  in Pa s

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

- Temperature range: from  $t_i$  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  $t_i$  to  $t_c$   
 Pressure range from  $p_i$  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  $t_i$  to  $t_{\max\_Ice}$   
 Pressure range from  $p_i$  to  $p_{\max\_Ice}$

Solidification curve: Temperature range from  $t_i$  to  $t_{\max}$   
 Pressure range from  $p_i$  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  $p > p_{\max}$
- $t < t_{\min}$  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: [1], [2]

**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**

### 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: [1]

**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**

### 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  $\kappa = \frac{w^2}{p^* v}$

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

Temperature range: from  $t_i$  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  $t_i$  to  $t_c$   
 Pressure range from  $p_i$  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  $t_i$  to  $t_{\max\_Ice}$   
 Pressure range from  $p_i$  to  $p_{\max\_Ice}$

Solidification curve: Temperature range from  $t_i$  to  $t_{\max}$   
 Pressure range from  $p_i$  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: [1]

**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**

### 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  $\lambda$  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: [1], [2]



**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**

### 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<sup>2</sup>/s

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

Temperature range: from  $t_i$  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  $t_i$  to  $t_c$

Pressure range from  $p_i$  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  $t_i$  to  $t_{\max\_Ice}$

Pressure range from  $p_i$  to  $p_{\max\_Ice}$

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

Pressure range from  $p_i$  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: [1], [2]

**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**

**Input Values**

**T** - Temperature  $t$  in °C

**Result**

**PMELCO2, PMEL** or **pmel\_t\_CO2** – Melting pressure  $p_{\text{mel}}$  in bar

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

Temperature range: from  $t_i$  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  $t < t_i$  or  $t > t_{\text{mel}}(p_{\text{max}})$

**References:** [1]

**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**

**Input Values**

**T** - Temperature  $t$  in °C

**Result**

**PSUBCO2, PSUB** or **psub\_t\_CO2** – Sublimation pressure  $p_{\text{sub}}$  in bar

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

Temperature range: from  $t_{\text{min}}$  to  $t_c$

**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:** [1]

**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**

### 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: [1], [2]

## 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**

### 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  $t_k$  to  $t_c$

### Results for wrong input values

Result **PSTCO2 = -1000, PS = -1000** or **ps\_t\_CO2 = -1000** for input values:

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

### References: [1]

**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**

### 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  $\rho$  in kg/m<sup>3</sup>

### 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 **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: [1]

**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**

### 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  $t_b$  to  $t_c$

Pressure range from  $p_b$  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  $t_b$  to  $t_{\max\_Ice}$

Pressure range from  $p_b$  to  $p_{\max\_Ice}$

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

Pressure range from  $p_b$  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: [1]

**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**

### 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: [1]

## 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**

### 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: [1]

**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**

**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:** [1]

**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**

### Input Values

**P** – Pressure  $p$  in bar

### Result

**TMELCO2, TMEL** or **tmel\_p\_CO2** – Melting temperature  $t_{\text{mel}}$  in °C

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

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

### 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: [1]

**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**

### Input Values

**P** – Pressure  $p$  in bar

### Result

**TSUBCO2, TSUB** or **tsub\_p\_CO2** – Sublimation temperature  $t_{\text{sub}}$  in °C

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

Pressure range: from  $p_{\text{min}}$  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: [1]



**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**

### 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 m<sup>3</sup>/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: [1]

**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**

### 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  $t > t_c$
- 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: [1]

## 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**

### 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: [1]

**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**

### 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: [1]

## Compression factor $z = f(p, t, x)$

Function Name: **z\_ptx\_CO2**

Subprogram with value of the function: **REAL\*8 FUNCTION ZPTXCO2(P,T,X)**  
 for call from Fortran **REAL\*8 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

**ZPTXCO2, Z or z\_ptx\_CO2** – Compression factor

### Range of Validity (z. $p, t$ -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 (z. 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 **ZPTXCO2 = -1000** or **z\_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: [1]



### 3.3 Property Functions for Solid Carbon Dioxide (Dry Ice)

#### 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**

#### Input Values

**P** - Pressure  $p$  in bar

**T** - Temperature  $t$  in °C

#### Result

**AICEPTCO2**, **a** or **alCE\_pt\_CO2** – Thermal diffusivity  $a = \frac{\lambda * v}{c_p}$  in m<sup>2</sup>/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 **AICEPTCO2 = -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:** [3], [4]

## 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**

### 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: [3]

**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**

**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:** [3]

**Thermal Conductivity  $\lambda = f(t)$** 

Function Name: **lambdalCE\_t\_CO2**

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

**Input Values**

**T** - Temperature  $t$  in °C

**Result**

**LAMICETCO2, LAM** or **lambdalCE\_t\_CO2** – Thermal conductivity  $\lambda$  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 **lambdalCE\_t\_CO2 = -1000** for input values:

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

**References:** [4]

## 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**

### Input Values

**P** - Pressure  $p$  in bar

**T** - Temperature  $t$  in °C

### Result

**RHOICEPTCO2, RHO or rhoICE\_pt\_CO2** - Density  $\rho$  in kg/m<sup>3</sup>

### 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: [3]

**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**

**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:** [3]

## 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**

### Input Values

**P** - Pressure  $p$  in bar

**T** - Temperature  $t$  in °C

### Result

**VICEPTCO2, V** or **vICE\_pt\_CO2** – specific volume  $v$  in m<sup>3</sup>/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: [3]

**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**

### 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: [3]



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

Function Name: **tICE\_ps\_CO2**

Subprogram with value of the function: **REAL\*8 FUNCTION TICEPSO2(P,S)**  
 for call from Fortran **REAL\*8 P,S**

### Input Value

**P** - Pressure  $p$  in bar

**S** – Specific Entropy in kJ/(kg K)

### Result

**TICEPSO2, 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 **TICEPSO2 = -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: [3]

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

### Water and Steam

#### Library LibIF97

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

#### Library LibIF97\_META

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

### Humid Combustion Gas Mixtures

#### Library LibHuGas

- Model: Ideal mixture of the real fluids:  
 $\text{CO}_2$  - Span, Wagner  $\text{H}_2\text{O}$  - IAPWS-95  
 $\text{O}_2$  - Schmidt, Wagner  $\text{N}_2$  - Span et al.  
 Ar - Tegeler et al.  
 and of the ideal gases:  
 $\text{SO}_2$ ,  $\text{CO}$ , Ne  
 (Scientific Formulation of Bücker et al.)  
 Consideration of:  
 • Dissociation from VDI 4670  
 • Poynting effect

### Humid Air

#### Library LibHuAir

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

### Extremely Fast Property Calculations

Spline-Based Table  
 Look-up Method (SBTL)

#### Library LibSBTL\_IF97 Library LibSBTL\_95 Library LibSBTL\_HuAir

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

### Carbon Dioxide Including Dry Ice

#### Library LibCO2

Formulation of Span and Wagner (1996)

### Seawater

#### Library LibSeaWa

IAPWS Industrial Formulation 2013

### Ice

#### Library LibICE

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

### Ideal Gas Mixtures

#### Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

Ar	NO	He	Propylene
Ne	$\text{H}_2\text{O}$	$\text{F}_2$	Propane
$\text{N}_2$	$\text{SO}_2$	$\text{NH}_3$	Iso-Butane
$\text{O}_2$	$\text{H}_2$	Methane	n-Butane
CO	$\text{H}_2\text{S}$	Ethane	Benzene
$\text{CO}_2$	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](http://www.ashrae.org/bookstore)

### Dry Air Including Liquid Air

#### Library LibRealAir

Formulation of Lemmon et al. (2000)

### Refrigerants

#### Ammonia

#### Library LibNH3

Formulation of Tillner-Roth et al. (1993)

#### R134a

#### Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

#### Iso-Butane

#### Library LibButane\_Iso

Formulation of Bücker and Wagner (2006)

#### n-Butane

#### Library LibButane\_n

Formulation of Bücker and Wagner (2006)

### Mixtures for Absorption Processes

#### Ammonia/Water Mixtures

#### Library LibAmWa

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

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

#### Water/Lithium Bromide Mixtures

#### Library LibWaLi

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

### Liquid Coolants

#### Liquid Secondary Refrigerants

#### Library LibSecRef

Liquid solutions of water with

$\text{C}_2\text{H}_6\text{O}_2$	Ethylene glycol
$\text{C}_3\text{H}_8\text{O}_2$	Propylene glycol
$\text{C}_2\text{H}_5\text{OH}$	Ethanol
$\text{CH}_3\text{OH}$	Methanol
$\text{C}_3\text{H}_8\text{O}_3$	Glycerol
$\text{K}_2\text{CO}_3$	Potassium carbonate
$\text{CaCl}_2$	Calcium chloride
$\text{MgCl}_2$	Magnesium chloride
$\text{NaCl}$	Sodium chloride
$\text{C}_2\text{H}_3\text{KO}_2$	Potassium acetate
$\text{CHKO}_2$	Potassium formate
$\text{LiCl}$	Lithium chloride
$\text{NH}_3$	Ammonia

Formulation of the International Institute of Refrigeration (IIR 2010)

### Ethanol

#### Library LibC2H5OH

Formulation of  
Schroeder et al. (2014)

### Methanol

#### Library LibCH3OH

Formulation of  
de Reuck and Craven (1993)

### Propane

#### Library LibPropane

Formulation of  
Lemmon et al. (2009)

### Siloxanes as ORC Working Fluids

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

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

Tetradecamethylhexasiloxane  $C_{14}H_{42}O_6Si_6$  **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 and Oxygen

#### Libraries LibN2 and LibO2

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

### Hydrogen

#### Library LibH2

Formulation of  
Leachman et al. (2009)

### Helium

#### Library LibHe

Formulation of  
Arp et al. (1998)

### Hydrocarbons

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

Isopentane  $C_5H_{12}$  **Library LibC5H12\_Iso**

Neopentane  $C_5H_{12}$  **Library LibC5H12\_Neo**

Isohexane  $C_6H_{14}$  **Library LibC6H14**

Toluene  $C_7H_8$  **Library LibC7H8**

Formulation of Lemmon and Span (2006)

### Further Fluids

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

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

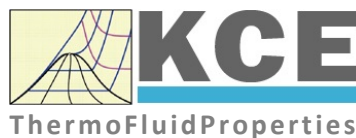
Hydrogen sulfide **H<sub>2</sub>S** **Library LibH2S**

Nitrous oxide **N<sub>2</sub>O** **Library LibN2O**

Sulfur dioxide **SO<sub>2</sub>** **Library LibSO2**

Acetone  $C_3H_6O$  **Library LibC3H6O**

Formulation of Lemmon and Span (2006)



### For more information please contact:

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

Internet: [www.thermofluidprop.com](http://www.thermofluidprop.com)  
Email: [info@thermofluidprop.com](mailto:info@thermofluidprop.com)  
Phone: +49-351-27597860  
Mobile: +49-172-7914607  
Fax: +49-3222-1095810

## The following thermodynamic and transport properties can be calculated<sup>a</sup>:

### Thermodynamic Properties

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

### Transport Properties

- Dynamic viscosity  $\eta$
- Kinematic viscosity  $\nu$
- Thermal conductivity  $\lambda$
- Prandtl number  $Pr$
- Thermal diffusivity  $a$

### Backward Functions

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

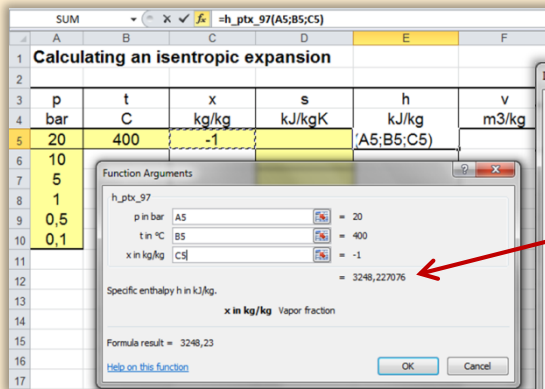
### Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

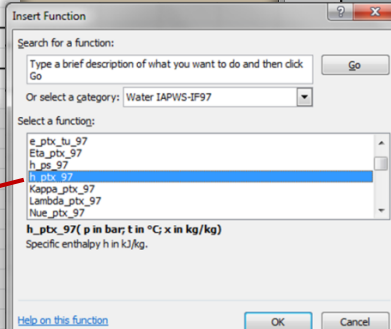
<sup>a</sup> Not all of these property functions are available in all property libraries.

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

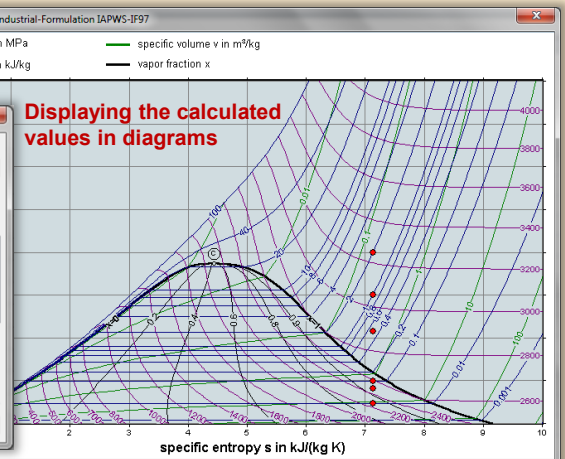
Add-In **FluidEXL** Graphics for Excel®



Choosing a property library and a function



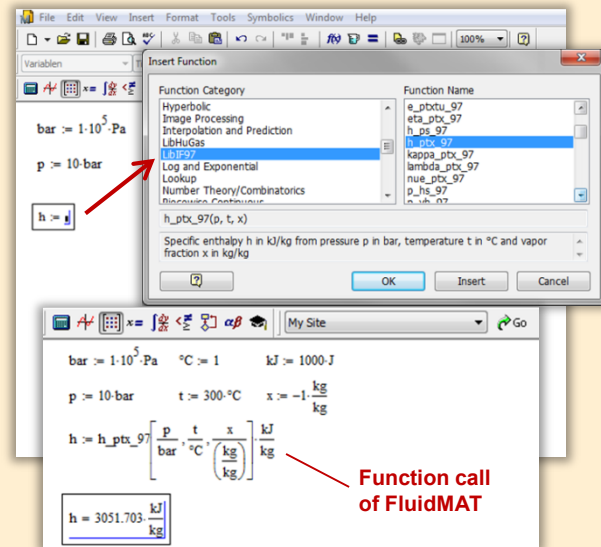
Displaying the calculated values in diagrams



Menu for the input of given property values

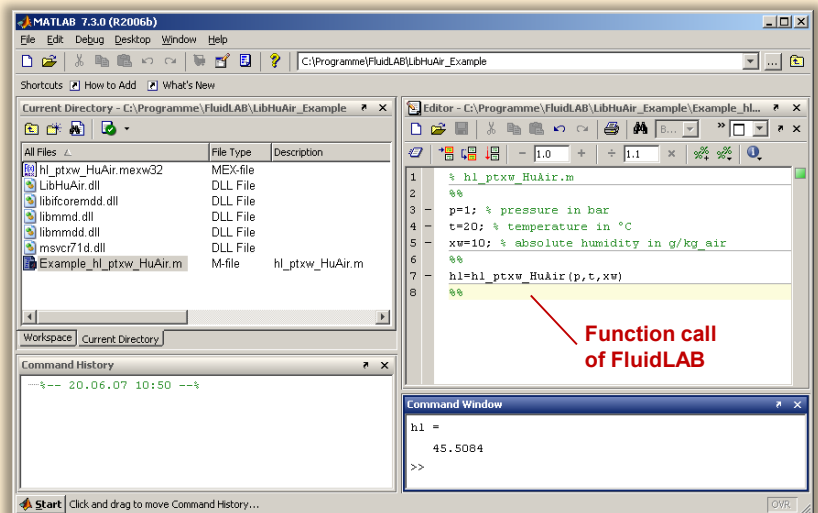
Add-On **FluidMAT** for Mathcad®  
 Add-On **FluidPRIME** for Mathcad Prime®

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



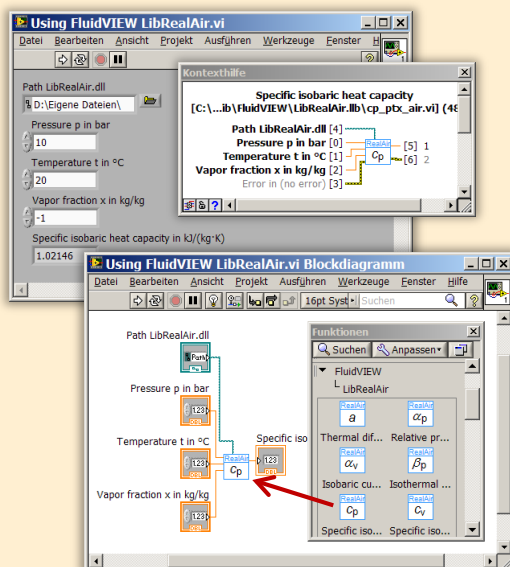
Add-On **FluidLAB** for MATLAB® and SIMULINK®

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



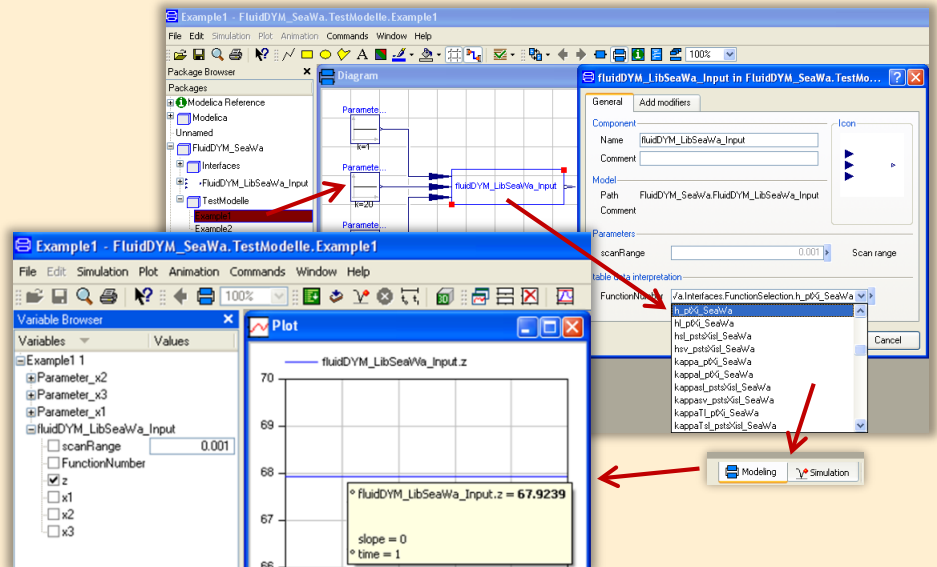
Add-On **FluidVIEW** for LabVIEW™

The property functions can be calculated in LabVIEW™.



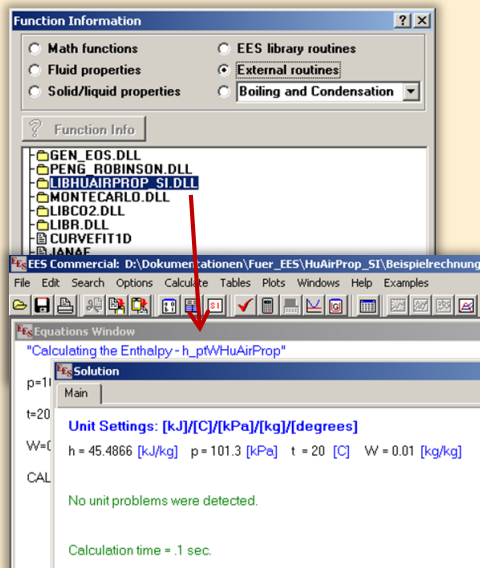
Add-On **FluidDYM** for DYMOLA® (Modelica) and SimulationX®

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

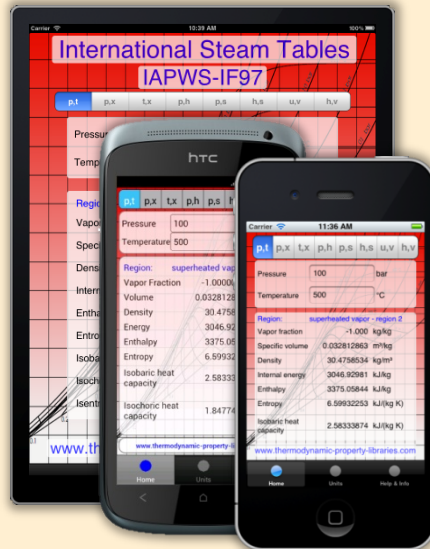




## Add-On **FluidEES** for Engineering Equation Solver®



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



## Online Property Calculator at [www.thermofluidprop.com](http://www.thermofluidprop.com)

**Zittau's Fluid Property Calculator**

Fluid:

Function:

Unit System:

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

Pressure p:  bar

Temperature t:  °C

Vapor fraction x:  kg/kg

**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

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Prof. Hans-Joachim Kretzschmar  
Dr. Ines Stoecker  
Programmer: Joachim Posselt

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E-mail: [info@thermofluidprop.com](mailto:info@thermofluidprop.com)  
[www.thermofluidprop.com](http://www.thermofluidprop.com)  
[www.thermofluidprop.com](http://www.thermofluidprop.com)  
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[www.thermofluidprop.com](http://www.thermofluidprop.com)

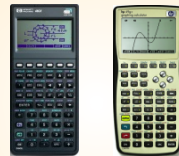
## Property Software for Pocket Calculators

### FluidCasio



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

### FluidHP



HP 48    HP 49

### FluidTI



TI Nspire CX CAS    TI 83    TI 89



TI Voyage 200



TI 92

## For more information please contact:



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Phone: +49-351-27597860  
Mobile: +49-172-7914607  
Fax: +49-3222-1095810

The following thermodynamic and transport properties<sup>a</sup> 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  $\rho$
- Specific volume  $v$
- Enthalpy  $h$
- Internal energy  $u$
- Entropy  $s$
- Exergy  $e$
- Isobaric heat capacity  $c_p$
- Isochoric heat capacity  $c_v$
- Isentropic exponent  $\kappa$
- Speed of sound  $w$
- Surface tension  $\sigma$

### Transport Properties

- Dynamic viscosity  $\eta$
- Kinematic viscosity  $\nu$
- Thermal conductivity  $\lambda$
- Prandtl number  $Pr$
- Thermal diffusivity  $\alpha$

### Backward Functions

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

### Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

<sup>a</sup> Not all of these property functions are available in all property libraries.

## 5. References

- [1] 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
- [2] Vesovic, V.; Wakeham, W. A.; Olchoway, 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
- [3] 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
- [4] Kuprianoff, J.:  
Die feste Kohlensäure (Trockeneis) – Herstellung und Verwendung  
Ferdinand Enke Verlag Stuttgart, 1953

## 6. Satisfied Customers

Period from 2018 to 2022

The following companies and institutions use the property libraries:

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

### 2022

ASTG, Graz, Austria	12/2022
Wandschneider + Gutjahr, Hamburg	
RWE Supply & Trading, Essen	11/2022
Stadtwerke Rosenheim	
CEA, Saclay, France	10/2022
RWE Supply & Trading, Essen	
SEEC Saudi Energy Efficiency Center, Riyadh, Saudi Arabia	
MAN, Copenhagen, Denmark	
Hermeler & Partner Consulting Engineers, Sassenberg	09/2022
Envi Con, Nürnberg	
Drill Cool Systems, Bakersfield CA, USA	
RWE Supply & Trading, Essen	
Maerz Ofenbau, Zürich, Switzerland	
Saale Energie, Schkopau	
ERGO, Dresden	
Mainova, Frankfurt/Main	
Bundeswehr, Koblenz	08/2022
RWE Supply & Trading, Essen	
Grenzebach Corporation, Newnan GE, USA	
AGRANA, Gmuend, Austria	07/2022
MIBRAG, Zeitz	
Hochschule Niederrhein, Krefeld	
ULT, Löbau	06/2022
LEAG, Cottbus	
VPC Group, Vetschau	

Wärme, Hamburg	
ILK, Dresden	
Stricker IB, Küssnacht a. Rigi, Switzerland	
LEAG, Cottbus	05/2022
RWE Supply & Trading, Essen	
IGT Tomalla, Kreuztal	
B+T Engineering, Dübendorf, Switzerland	
Stricker IB, Küssnacht a. Rigi, Switzerland	
Vogelsang & Benning, Bochum	04/2022
Frischli, Rehburg-Loccum	
BPS Consulting, Sprengel	03/2022
HS Hannover, Maschinenbau & BioVT	
M+M Turbinentechnik, Bad Salzungen	
Uni. Strathclyde, Glasgow, UK	02/2022
Delta Energy Group, Jiaozhou City, Qingdao, China	
Wetzel IB, Guben	
Wijbenga, PC Geldermalsen, The Netherlands	
Voith Paper, Heidenheim	
HS Zittau/Görlitz, Maschinenwesen	01/2022
Thermische Abfallbehandlung, Lauterbach	
Webb Institute, Glen Cove NY, USA	
TU Berlin, Umweltverfahrenstechnik	
SachsenEnergie, Dresden	
Doosan, Chang-won-si, Gyeongsangnam-do, South Korea	
KW3, LH Veenendaal, The Netherlands	
Université du Luxembourg, Esch-sur-Alzette	
Enseleit IB, Mansfeld	
Caliqua/Equans, Zürich, Switzerland	
Rudnick & Enners, Alpenrod	

## 2021

Wenisch IB, Vetschau	12/2021
PPCHEM, Hinwil, Switzerland	
KW3, The Netherlands	
BASF Ludwigshafen	
Air-Consult, Jena	
Sjerp & Jongeneel, RB Zoetermeer, The Netherlands	11/2021
Maerz Ofenbau, Zürich, Switzerland	
RWE Supply & Trading, Essen	
Hahn IB, Dresden	10/2021
Therm, South Africa	
RWE Supply & Trading, Essen	
TH Nürnberg, Verfahrenstechnik	09/2021
RWE Supply & Trading, Essen	
Enseleit IB, Mansfeld	
SachsenEnergie, Dresden	
BSH Hausgeräte, Berlin	



Norsk Energi, Oslo, Norway	08/2021
AKM Industrieanlagen, Haltern	
Drill Cool Systems, Bakersfield CA, USA	
Siemens Energy Global, Erlangen	07/2021
Wulff & Umag, Husum	
Planungsbüro Waidhas, Chemnitz	
Burkhardt Energie Technik, Mühlhausen	
Lücke IB, Paderborn	06/2021
TU Dresden, Energieverfahrenstechnik	
Wärme, Hamburg	
AL-KO Therm, Kötz	
PCK Raffinerie, Schwedt	
Vogelsang & Benning, Bochum	05/2021
MTU, München	
VPC Group, Vetschau	
AVG, Köln	04/2021
TH Ulm, Institut für Fahrzeugtechnik	
Marty IB, Oberwil, Switzerland	
HypTec, Lebring, Austria	
Lopez IB, Getxo, Bizkaia, Spain	03/2021
GM Remediation Systems, Leoben, Austria	
Jager Kältetechnik, Osnabrück	
T&M Automation, GR Leidschendam, The Netherlands	
RWE Supply & Trading, Essen	
Stadtwerke Leipzig	
Beuth Hochschule für Technik, Berlin	
Beleth IB, Woeth	02/2021
ZTL, Thal, Austria	
ETABO Bochum	
RWE Supply & Trading, Essen	
Onyx Germany, Berlin	
TU Dresden, Kältetechnik	
GOHL-KTK, Durmersheim	
Therm Development, South Africa	
thermofin, Heinsdorfergrund	
RWE Supply & Trading, Essen	01/2021
STEAG, Essen	
ETA Energieberatung, Pfaffenhofen	
Enex Power, Kirchseeon	

## 2020

Drill Cool, Bakersfield CA, USA	12/2020
Manders, The Netherlands	
RWE Supply & Trading, Essen	
NEOWAT Lodz, Poland	
University of Duisburg-Essen, Duisburg	11/2020
Stellenbosch University, South Africa	

University De France-COMTe, France	
RWE, Essen	
STEAG, Herne	
Isenmann Ingenieurbüro	
University of Stuttgart, ITLR, Stuttgart	
Norsk Energi, Oslo, Norway	
TGM Kanis, Nürnberg	
Stadtwerke Neuburg	10/2020
Smurfit Kappa, Roermond, The Netherlands	
RWE, Essen	
Hochschule Zittau/Görlitz, Wirtschaftsingenieurwesen	
Stadtwerke, Neuburg	
ILK, Dresden	
ATESTEO, Alsdorf	
Hochschule Zittau/Görlitz, Maschinenwesen	
TH Nürnberg, Verfahrenstechnik	
Drill Cool, Bakersfield CA, USA	09/2020
RWE, Essen	
2Meyers Ingenieurbüro, Nürnberg	
FELUWA, Mürlenbach	
Stadtwerke Neuburg	
Caverion, Wien, Austria	
GMVA Niederrhein, Oberhausen	
INWAT Lodz, Poland	
Troche Ingenieurbüro, Hayingen	08/2020
CEA Saclay, France	
VPC, Vetschau	07/2020
FSK System-Kälte-Klima, Dortmund	
Exergie Etudes, Sarl, Switzerland	
AWG Wuppertal	
STEAG Energy Services, Zwingenberg	
Hochschule Braunschweig	06/2020
DBI, Leipzig	
GOHL-KTK, Dumersheim	
TU Dresden, Energieverfahrenstechnik	
BASF SE, ESI/EE, Ludwigshafen	
Wärme Hamburg	
Ruchti Ingenieurbüro, Uster, Switzerland	
IWB, Basel, Switzerland	
Midiplan, Bietingen-Bissingen	05/2020
Knieschke, Ingenieurbüro	
RWE, Essen	
Leser, Hamburg	
AGRANA, Gmünd, Austria	
EWT Wassertechnik, Celle	
Hochschule Darmstadt	04/2020
MTU München CCP	
HAW Hamburg	03/2020

Hanon, Novi Jicin, Czech Republic	
TU Dresden, Kältetechnik	
MAN, Copenhagen, Denmark	
EnerTech, Radebeul	02/2020
LEAG, Cottbus	
B+B Engineering Magdeburg	
Hochschule Offenburg	
WIB, Dennheritz	01/2020
Universität Duisburg-Essen, Strömungsmaschinen	
Kältetechnik Dresden-Bremen	
TH Ingolstadt	
Vattenfall AB, Jokkmokk, Sweden	
Fraunhofer UMSICHT	

## 2019

PEU Leipzig, Rötha	12/2019
MB-Holding, Vestenbergsgreuth	
RWE, Essen	
Georg-Büchner-Hochschule, Darmstadt	11/2019
EEB ENERKO, Aldenhoven	
Robert Benoufa Energietechnik, Wiesloch	
Kehrein & Kubanek Klimatechnik, Moers	10/2019
Hanon Systems Autopal Services, Hluk, Czech Republic	
CEA Saclay, Gif Sur Yvette cedex, France	
Saudi Energy Efficiency Center SEEC, Riyadh, Saudi Arabia	
VPC, Vetschau	09/2019
jGanser PM + Engineering, Forchheim	
Endress+Hauser Flowtec AG, Reinach, Switzerland	
Ruchti IB, Uster, Switzerland	
ZWILAG Zwischenlager Würenlingen, Switzerland	08/2019
Hochschule Zittau/Görlitz, Faculty Maschinenwesen	
Stadtwerke Neubrandenburg	
Physikalisch Technische Bundesanstalt PTB, Braunschweig	
GMVA Oberhausen	07/2019
Endress+Hauser Flowtec AG, Reinach, Switzerland	
WARNICA, Waterloo, Canada	
MIBRAG, Zeitz	06/2019
Pöyry, Zürich, Switzerland	
RWTH Aachen, Institut für Strahlantriebe und Turbomaschinen	
Midiplan, Bietigheim-Bissingen	
GKS Schweinfurt	
HS Zittau/Görlitz, Wirtschaftswissenschaften und Wirtschaftsingenieurwesen	
ILK Dresden	
HZDR Helmholtz Zentrum Dresden-Rossendorf	
TH Köln, Technische Gebäudeausrüstung	05/2019
IB Knittel, Braunschweig	
Norsk Energi, Oslo, Norway	

STEAG, Essen	
Stora Enso, Eilenburg	
IB Lücke, Paderborn	
Haarslev, Sonderso, Denmark	
MAN Augsburg	
Wieland Werke, Ulm	04/2019
Fels-Werke, Elbingerode	
Univ. Luxembourg, Luxembourg	
BTU Cottbus, Power Engineering	03/2009
Eins-Energie Sachsen, Schwarzenberg	
TU Dresden, Kälte- und Kryotechnik	
ITER, St. Paul Lez Durance Cedex, France	
Fraunhofer UMSICHT, Oberhausen	
Comparex Leipzig for Spedition Thiele HEMMERSBACH	
Rückert NaturGas, Lauf/Pegnitz	
BASF, Basel, Switzerland	02/2019
Stadtwerke Leipzig	
Maerz Ofenbau Zürich, Switzerland	
Hanon Systems Germany, Kerpen	
Thermofin, Heinsdorfergrund	01/2019
BSH Berlin	

## 2018

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

GRS, Köln	
WIB, Dennheritz	
RONAL AG, Härklingen, Schweiz	02/2018
Ingenieurbüro Leipert, Riegelsberg	
AIXPROCESS, Aachen	
KRONES, Neutraubling	
Doosan Lentjes, Ratingen	01/2018