

Property Library for Carbondioxid

FluidMAT
with LibCO₂
for Mathcad®

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Software for the Calculation of the Properties of Carbondioxid

FluidMAT LibCO2

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0 Package Contents

Zip-file "CD_FluidMAT_LibCO2.zip" includes the following files:

FluidMAT_LibCO2_Setup.exe	- Self-extracting and self-installing program
LibCO2.dll	- DLL with functions of the LibCO2 library
FluidMAT_LibCO2_Docu.pdf	- User's Guide

1. Property Functions

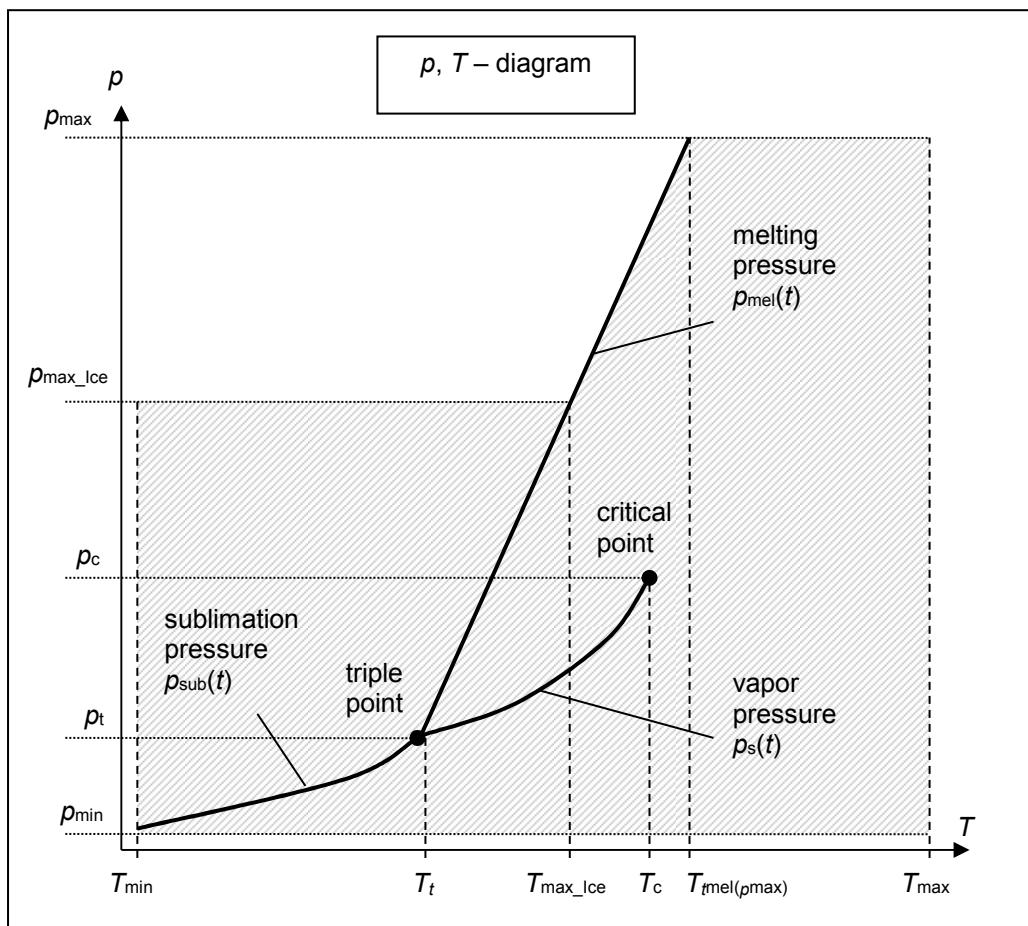
Units:

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	$T_{\text{mel}}(p_{\max}) (t_{\text{mel}}(p_{\max}))$	327.671 K (54.521 °C)
Minimum pressure	$p_{\min} = p_{\text{sub}}(T_{\min})$	$2.9081875815 \cdot 10^{-10}$ 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	Call from the DLL LibCO2 as Parameter	Property or Function	Unit of the Result
$a = f(p,t,x)$	a_ptx_CO2	APTXCO2(P,T,X)	C_APTXCO2(A,P,T,X)	Thermal diffusivity	m ² /s
$c_p = f(p,t,x)$	cp_ptx_CO2	CPPTXCO2(P,T,X)	C_CPPTXCO2(CP,P,T,X)	Specific isobaric heat capacity	kJ/(kg K)
$\eta = f(p,t,x)$	eta_ptx_CO2	ETAPTCO2(P,T,X)	C_ETAPTCO2(ETA,P,T,X)	Dynamic viscosity	Pa s
$h = f(p,t,x)$	h_ptx_CO2	HPTXCO2(P,T,X)	C_HPTXCO2(H,P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p,t,x)$	kappa_ptx_CO2	KAPTXCO2(P,T,X)	C_KAPTXCO2(KAP,P,T,X)	ISENTROPIC exponent	-
$\lambda = f(p,t,x)$	lambda_ptx_CO2	LAMPTCO2(P,T,X)	C_LAMPTXCO2(LAM,P,T,X)	Thermal conductivity	W/(m K)
$\nu = f(p,t,x)$	ny_ptx_CO2	NYPTXCO2(P,T,X)	C_NYPTXCO2(NY,P,T,X)	Kinematic viscosity	m ² /s
$p_{mel} = f(t)$	pmel_t_CO2	PMELCO2(T)	C_PMELCO2(PMEL,T)	Melting pressure from temperature	bar
$p_{sub} = f(t)$	psub_t_CO2	PSUBCO2(T)	C_PSUBCO2(PSUB,T)	Sublimation pressure from temperature	bar
$p_s = f(t)$	ps_t_CO2	PSTCO2(T)	C_PSTCO2(PS,T)	Vapor pressure from temperature	bar
$Pr = f(p,t,x)$	Pr_ptx_CO2	PRPTXCO2(P,T,X)	C_PRPTXCO2(PR,P,T,X)	Prandtl-Number	-
$\rho = f(p,t,x)$	rho_ptx_CO2	ROPTXCO2(P,T,X)	C_ROPTXCO2(RHO,P,T,X)	Density	kg/ m ³
$s = f(p,t,x)$	s_ptx_CO2	SPTXCO2(P,T,X)	C_SPTXCO2(S,P,T,X)	Specific entropy	kJ/(kg K)
$t = f(p,h)$	t_ph_CO2	TPHCO2(P,H)	C_TPHCO2(T,P,H)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p,s)$	t_ps_CO2	TPSCO2(P,S)	C_TPSCO2(T,P,S)	Backward function: Temperature from pressure and entropy	°C

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

Property Functions for Solid Carbon Dioxide (Dry Ice)

Functional Dependence	Function Name	Call from Fortran program	Call from the DLL LibCO2 as Parameter	Property or Function	Unit of the Result
$a = f(p,t)$	alICE_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_LAMICEPTCO2 (LAM,T)	Thermal conductivity	W/(m K)
$\rho = f(p,t)$	rholICE_pt_CO2	RHOICETCO2(P,T)	C_RHOICEPTCO2 (RHO, P, T)	Density	kg/ m³
$s = f(p,t)$	sICE_pt_CO2	SICETCO2(P,T)	C_SICEPTCO2 (S, P, T)	Specific entropy	kJ/ (kg K)

Functional Dependence	Function Name	Call from Fortran program	Call from the DLL LibCO2 as Parameter	Property or Function	Unit of the Result
$v = f(p,t)$	vICE_pt_CO2	VICETCO2(P,T)	C_VICEPTCO2 (V, P, T)	Specific volume	m ³ /kg
$t = f(p,h)$	tICE_ph_CO2	TICEHCO2(P,H)	C_TICEPHCO2 (T, P, H)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p,s)$	tICE_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 $T_{\text{max_Ice}} = 236.0309 \text{ K}$ ($t_{\text{max_Ice}} = -37.119 \text{ }^{\circ}\text{C}$) to $T_t = 216.592 \text{ K}$ ($t_t = -56.558 \text{ }^{\circ}\text{C}$)
 Pressure range from $p_t = 5.179618369088 \text{ bar}$ to $p_{\text{max_Ice}} = 1000 \text{ bar}$

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

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.

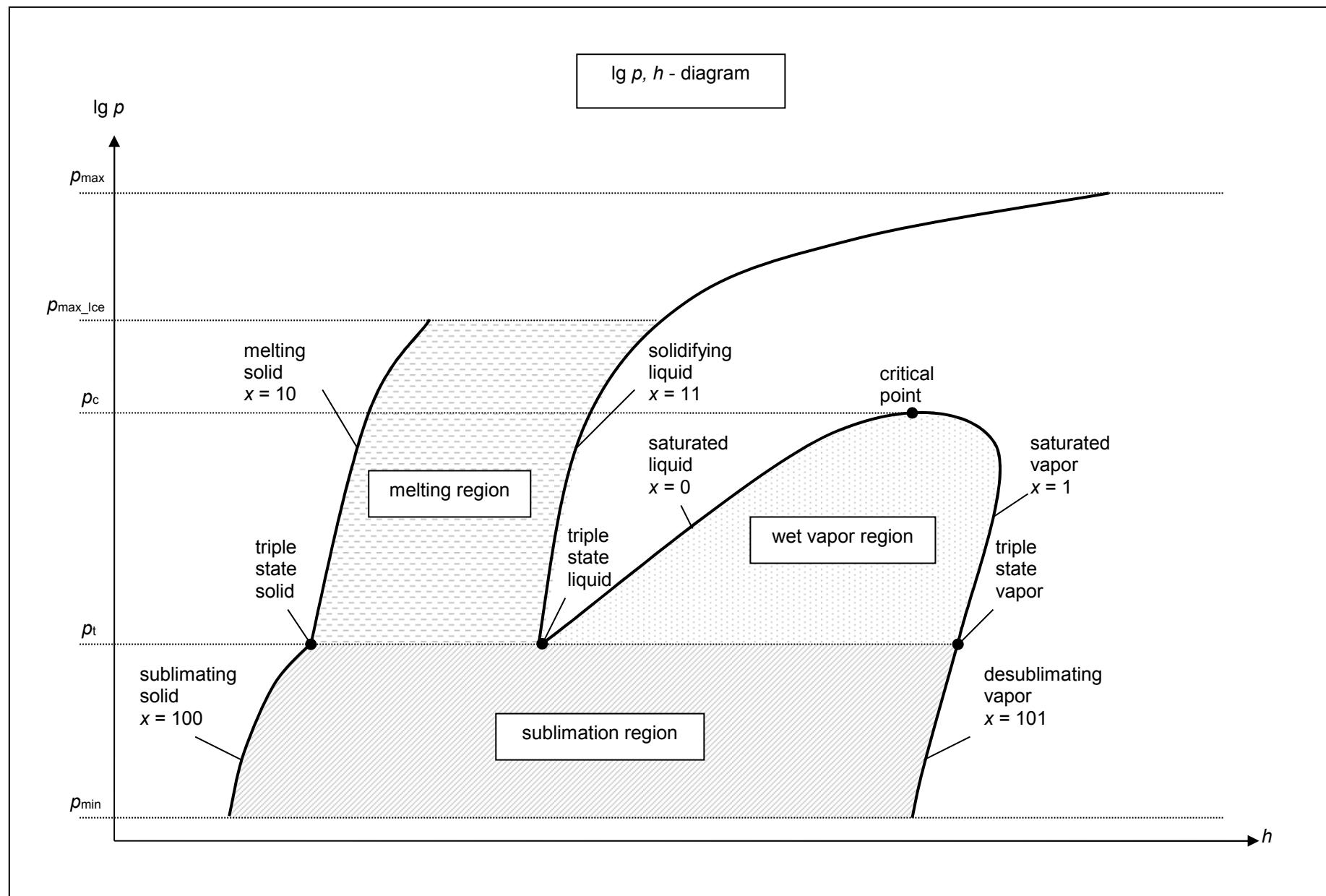
In this case it is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 100 and 101. If values for both p and t are entered, the program will consider p and t to be appropriate to represent the sublimation pressure curve. 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 $T_{\text{min}} = 85 \text{ K}$ ($t_{\text{min}} = -188.15 \text{ }^{\circ}\text{C}$) to $T_t = 216.592 \text{ K}$ ($t_t = -56.558 \text{ }^{\circ}\text{C}$)
 Pressure range from $p_{\text{min}} = 2.9081875815 \cdot 10^{-10} \text{ bar}$ 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 FluidMAT in Mathcad®

FluidMAT has been developed to calculate thermodynamic properties in Mathcad® more conveniently. Within Mathcad, it enables the direct call of functions relating to carbon dioxide from the LibCO2 property library.

2.1 Installing FluidMAT

In this section, the installation of FluidMAT LibCO2 is described.

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

After you have downloaded and extracted the zip-file "CD_FluidMAT_LibCO2_Eng.zip", you will see the folder

CD_FluidMAT_LibCO2_Eng

in your Windows Explorer, Norton Commander etc.

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

Within this folder you will see the following files:

FluidMAT_LibCO2_Docu_Eng.pdf

FluidMAT_LibCO2_Setup.exe

LibCO2.dll.

In order to run the installation of FluidMAT including the LibCO2 property library double-click the file

FluidMAT_LibCO2_Setup.exe.

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

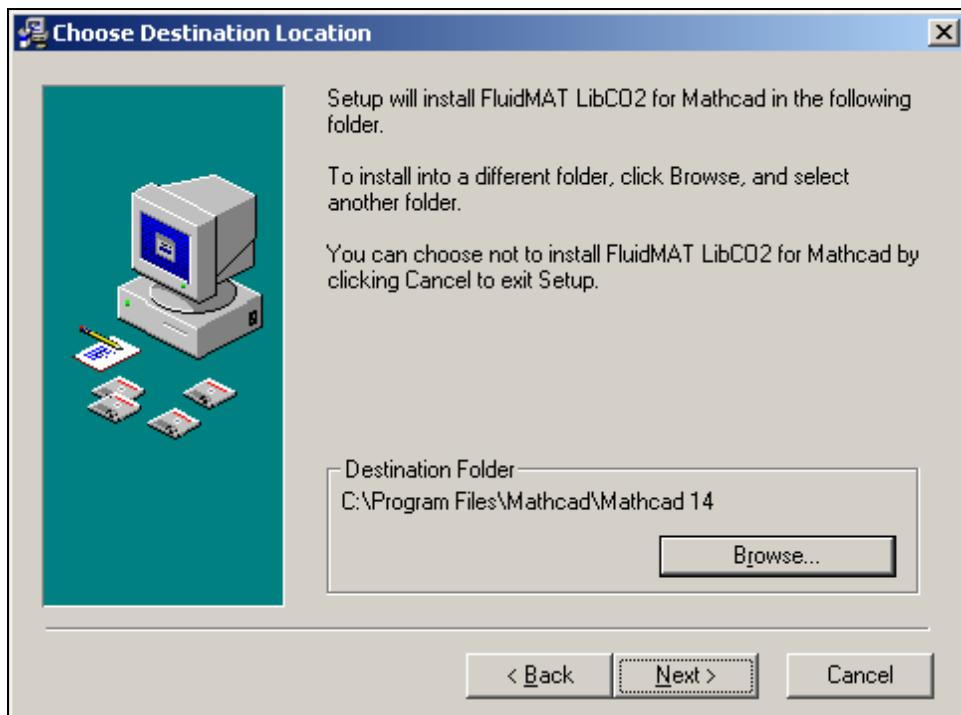
When this is the case, the installation can be continued. Click the "Next >" button.

Now, you will be informed on the FluidMAT product in the "ReadMe-File" window. Click "Next >" to leave this window.

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

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

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



The path will be displayed in the window.

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

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

After FluidMAT LibCO2 has been installed, the sentence "FluidMAT LibCO2 for Mathcad Professional has been successfully installed" will be shown.

Confirm this by clicking the "Finish >" button.

During the installation process the following files have been copied into the chosen destination folder (which is the folder, where Mathcad was installed):

advapi32.dll	Dynamic link library for use in Windows® programs
Dforrt.dll	Dynamic link library for use in Windows programs
Dformd.dll	Dynamic link library for use in Windows programs
LC.dll	Dynamic link library for use in Windows programs
LibCO2.dll	Property library for carbon dioxide
msvcp60.dll	Dynamic link library for use in Windows programs
Msvcrt.dll	Dynamic link library for use in Windows programs
Readme.txt	ReadMe file
INSTALL_MAT.LibCO2.LOG	Installation log-file

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

MAT.LibCO2.dll Function definition of LibCO2

The following files were installed into your Mathcad subdirectory \doc\funcdoc:

MAT_LibCO2_DE.xml	Function registration in the dialog window "Insert Function" for LibCO2 (German Mathcad version 12 or higher)
MAT_LibCO2_EN.xml	Function registration in the dialog window "Insert Function" for LibCO2 (English Mathcad version 12 or higher)
MAT_LibCO2.xml	Function registration in the dialog window "Insert Function" for LibCO2 (Mathcad version 11 or lower)

Now, you have to overwrite the file "LibCO2.dll" in your Mathcad directory with the file of the same name provided on your CD with FluidMAT.

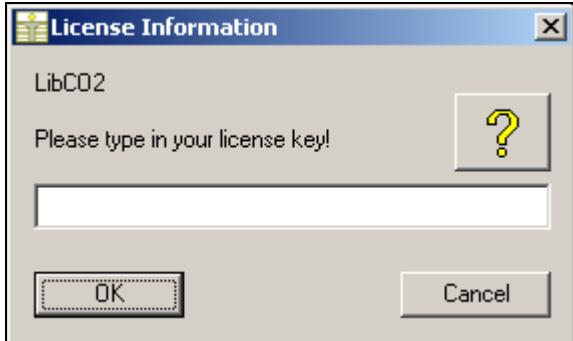
To do this, open the CD in "My Computer" and click on the file "LibCO2.dll" in order to highlight it. Then click on the "Edit" menu in your Explorer and select "Copy". Now, open your Mathcad directory (the standard being C:\Program Files\Mathcad\Mathcad 14) and insert the file "LibCO2.dll" by clicking the "Edit" menu in your Explorer and then select "Paste". Answer the question whether you want to replace the file by clicking the "Yes" button.

You have overwritten the file "LibCO2.dll" successfully.

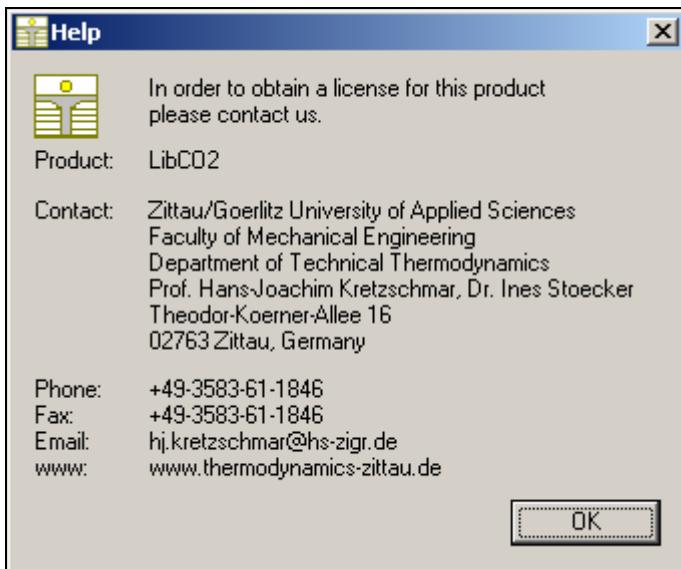
From within Mathcad you can now select the FluidMAT LibCO2 property functions.

Licensing the LibCO2 Property Library

The licensing procedure has to be carried out when you are calculating a function with LibCO2 in Mathcad® and a FluidMAT prompt message appears. In this case, you will see the "License Information" window for LibCO2 (see figure below).



Here you will have to type in the license key which you have obtained from Kretzschmar Consulting Engineers. 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:



If you do not enter a valid license it is still possible to use Mathcad by clicking "Cancel". In this case, the LibCO2 property library will display the result "-11111111" for every calculation.

The "License Information" window will appear every time you use the LibCO2 property library in Mathcad unless you uninstall FluidMAT according to the description in section 2.3 of this User's Guide.

Should you not wish to license the LibCO2 property library, you have to delete the files

LibCO2.dll	MAT_LibCO2_DE.xml
MAT_LibCO2.dll	MAT_LibCO2_EN.xml
	MAT_LibCO2.xml

in the installation folder of FluidMAT (the standard being

C:\Program Files\Mathcad\Mathcad 14

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

2.2 Example: Calculation of the Enthalpy $h = f(p,t,x)$ for Carbon dioxide

Now we will calculate, step by step, the specific enthalpy h as a function of pressure p , temperature t and vapor fraction x for carbon dioxide from the LibCO2 property library, using FluidMAT.

Please carry out the following instructions:

- Start Mathcad.
- Type "p:" and enter the value for pressure p in bar.
(Range of validity: $p = 2.9081875815 \cdot 10^{-10}$ bar ... 8000 bar)

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

Note:

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

- Type "t:" and enter the value for the temperature t in °C.
(Range of validity: $t = t_{\text{mel}} \dots 826.85$ °C)
e. g.: Enter "t:25", then press the tabulator key and enter "in °C."
- Type "x:" and enter the value for the vapor fraction x in $\text{kg}_{\text{sat. steam}} / \text{kg}_{\text{wet steam}}$.

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

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

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

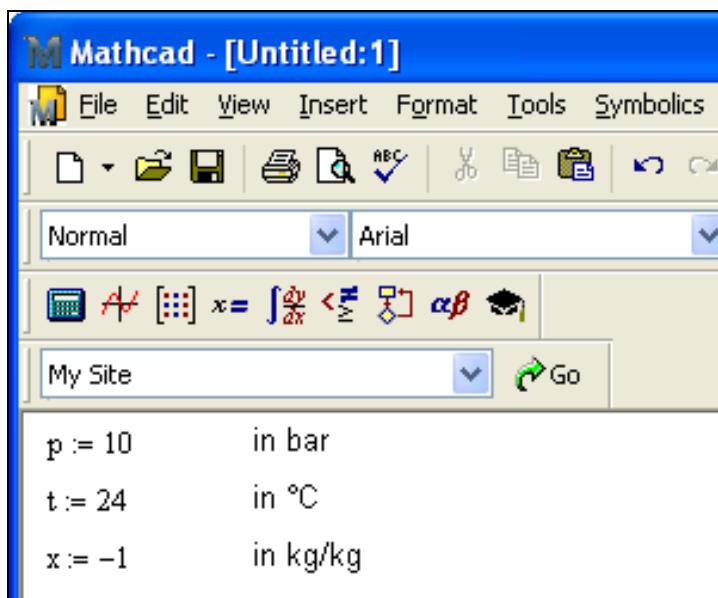
Here, it is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1.

If t and p and x are entered, the program will consider p and t to be appropriate to represent the saturation-line. If this is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

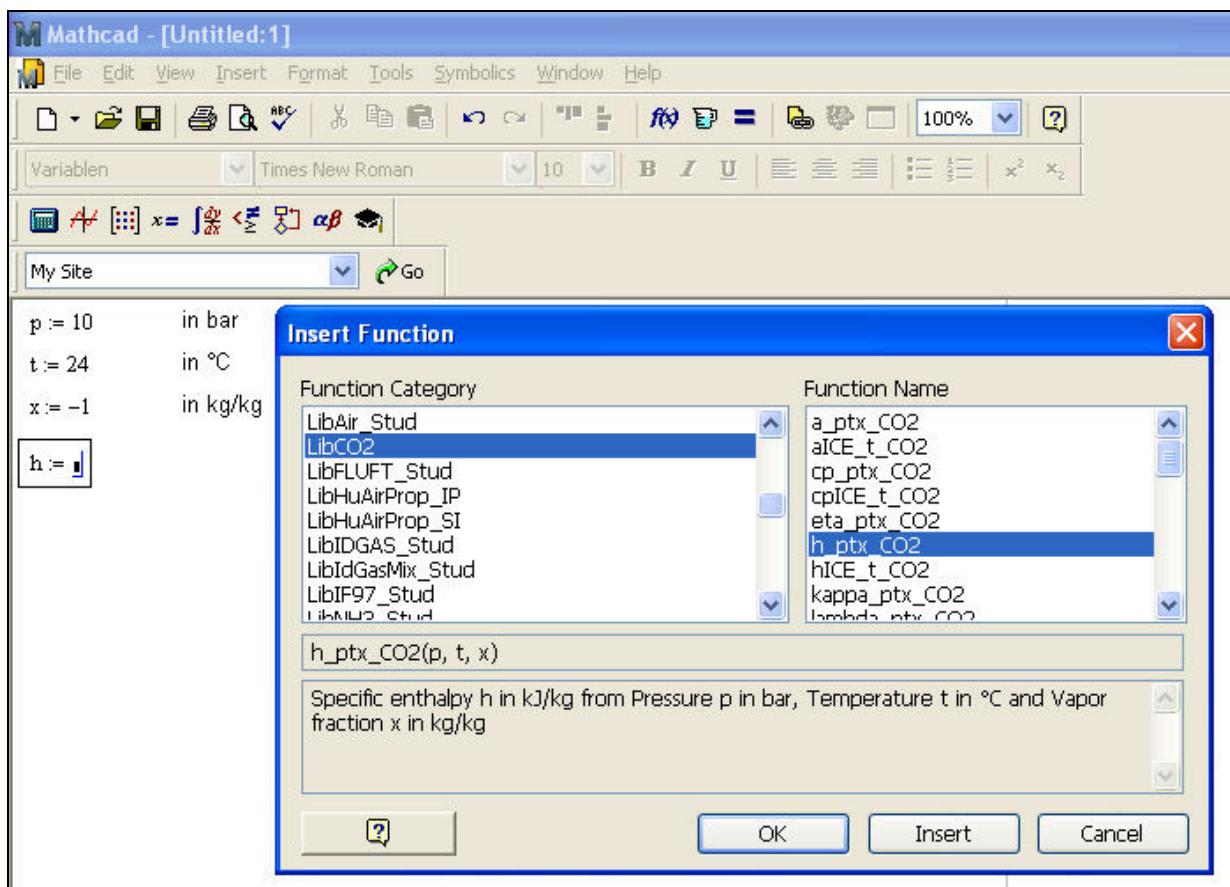
(CO2 saturation line: $t_t = -56.558$ °C ... $t_c = 30.9782$ °C
 $p_t = 5.179618369088$ bar ... $p_c = 73.773$ bar)

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

- Confirm your entry by pressing the "ENTER" key.
- Your Mathcad calculation window should like the following figure:



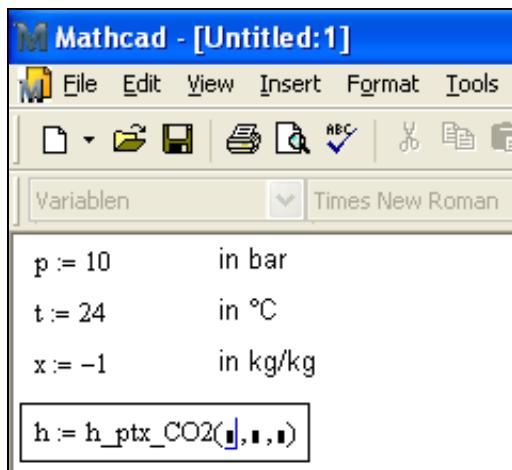
- Now, type "h:" in the Mathcad window. Now, you will see **h := ■**.
- Click on "Insert" in the upper menu bar and then click "Function...". Now, the "Insert function" window appears (see next figure).



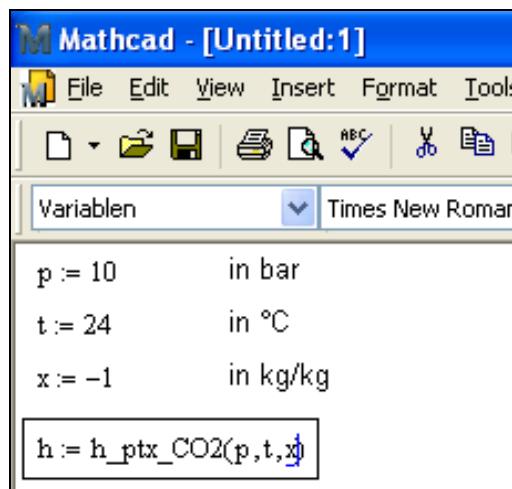
- Search and click the "LibCO2" library under "Function category" in the left part of the window.
- Now, search and click the "h_ptx_CO2" function under "Function name" on the right hand side of the window.

The function category and the function name will be inverted, highlighted and furthermore the description of the function and the measuring units of the variables are shown.

- Now, click "OK" and you will see $h := h_{\text{ptx_CO2}}(p, t, x)$ in the Mathcad window (see next figure).



- The cursor is situated on the first operand. You can now enter the value for p either by entering the value directly or by entering the name of the variable where the value was saved.
⇒ e.g.: Enter "p".
- Situate the cursor on the next placeholder. You can now enter the value for the temperature t either by entering the value for t directly or by typing the name of the variable in which the value of the temperature has been saved.
⇒ e.g.: Enter "t".
- Situate the cursor on the next placeholder. You can now enter the value for the humidity ratio x either by entering the value for x directly or by typing the name of the variable in which the value of the humidity ratio has been saved.
⇒ e.g.: Enter "x".
- Now, enter the unit of the enthalpy h after the brackets, by typing "*kJ/kg"
- Close the input formula by pressing the "Enter"-Key.
- Your Mathcad calculation window should like the following figure:

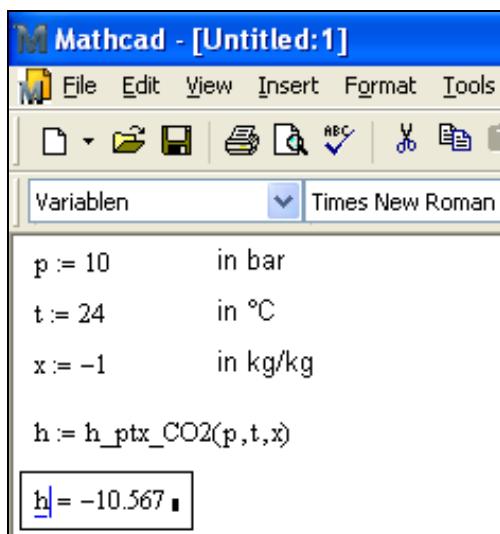


- You can now go on working with the variable h which we have just calculated or you can query the result. If you wish to see the result, you have to type the command " **$h=$** " on the next line in the Mathcad® window.

The result for h in kJ/kg appears. To add the unit, press the tabulator key twice and enter "in kJ/kg".

⇒ The result in our sample calculation here is: $h = -10.567$.

The representation of the result depends on the amount decimal places which you have set before.



2.3 Removing FluidMAT

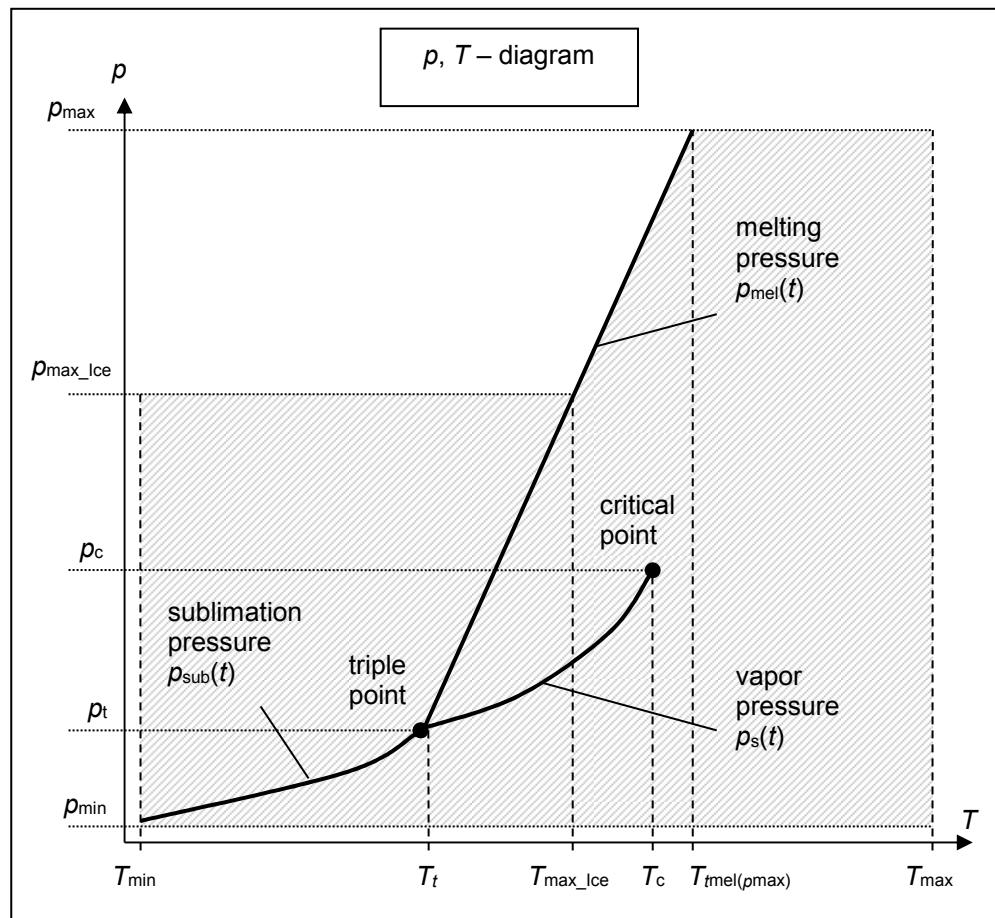
To remove FluidMAT from Mathcad® and from your hard disk drive, proceed as follows:

- Click "Start" in the lower task bar of your desktop, then "Settings" and then "Control Panel".
- Now, double click on "Add or Remove Programs".
- In the list box of the "Add or Remove Programs" window that appears select "FluidMAT LibCO2 for Mathcad Professional" by clicking on it and click the "Add/Remove..." button.
- In the following dialog box click "Automatic" and thereafter "Next >".
- Click "Finish" in the "Perform Uninstall" window.
- Finally, close the "Add or Remove Programs" and "Control Panel" windows.

Now FluidMAT has been removed.

3. Program Documentation

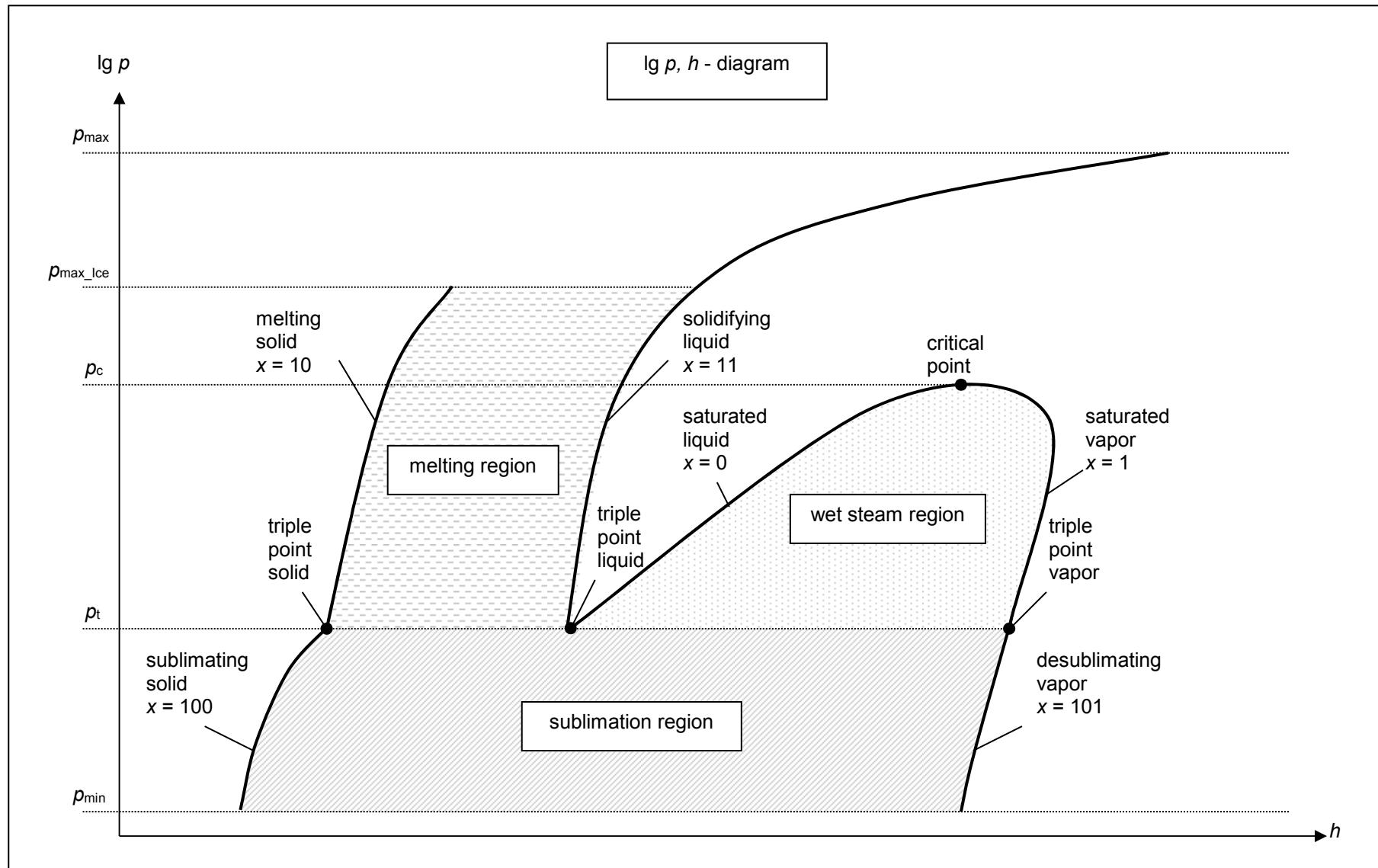
3.1 Ranges of Validity



Reference State:

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

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



3.2 General Property Functions

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

Function Name: **a_ptx_CO2**

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

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

Input Values

P – Pressure p in bar

T - Temperature t in °C

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

Result

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

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

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

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

Details on the phase fraction x

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

The two phase regions wet steam region, melting region and sublimation region are calculated automatically by the subprograms. For this purpose the following facts have to be considered (cp. 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_l to t_c
Pressure range from p_l 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_l to t_{\max_ice}

Pressure range from p_t to p_{\max_ice}

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

Pressure range from p_t to p_{\max}

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

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

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

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

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

When calculating a sublimating solid or desublimating steam it is adequate, Concerning pressure and temperature, to put in either the value given for t and $p = -1000$ or the value given for p and $t = -1000$ and the value for x ($x = 100$ or $x = 101$). If p and t 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 **APTXCO2 = -1000, A = -1000** or **a_ptx_CO2 = -1000** for input values:

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2], [3]

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

Function Name: **cp_ptx_CO2**

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

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

Input Values

P – Pressure p in bar

T - Temperature t in °C

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

Result

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

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

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

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

Details on the phase fraction x

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Sublimation and

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

Pressure range from p_{\min} to p_t

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2]

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

Function Name: **eta_ptx_CO2**

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

Subprogram with parameter:
for call from the DLL

INTEGER*4 FUNCTION C_ETAPTCO2(ETA,P,T,X)
REAL*8 ETA,P,T,X

Input Values

P – Pressure p in bar

T - Temperature t in °C

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

Result

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

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

Temperature range: from t_l 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_l 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_l to t_{max_ice}

Pressure range from p_t to p_{max_ice}

Solidification curve: Temperature range from t_l to t_{max}

Pressure range from p_t to p_{max}

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

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

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

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

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2], [3]

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

Function Name: **h_ptx_CO2**

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

Subprogram with parameter:
for call from the DLL

INTEGER*4 FUNCTION C_HPTXCO2(H,P,T,X)
REAL*8 H,P,T,X

Input Values

P – Pressure p in bar

T - Temperature t in °C

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

Result

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

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

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

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

Details on the phase fraction x

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

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

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

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

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

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

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

Boiling and dew curve: Temperature range from t_l to t_c
Pressure range from p_l 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_l to t_{\max_ice}

Pressure range from p_t to p_{\max_ice}

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

Pressure range from p_t to p_{\max}

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

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

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

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

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

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

Sublimation and

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

Pressure range from p_{\min} to p_t

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2]

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

Function Name: **kappa_ptx_CO2**

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

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

Input Values

P – Pressure p in bar

T - Temperature t in °C

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

Result

$$\text{KAP_PTX_CO2, KAP or kappa_ptx_CO2} - \text{Isentropic exponent } \kappa = \frac{w^2}{p * v}$$

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

Temperature range: from t_t to t_{\max}

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

Details on the phase fraction x

If the state point to be calculated is located in the single phase region (liquid or superheated steam), $x = -1$ must be entered as a pro-forma value. Calculating solid is not possible.

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

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

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

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

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

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

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

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

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

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

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

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 11 for x must be entered when calculating solidifying liquid.

If p and t and x are entered as given values, the program tests whether p and t fulfil the melting pressure curve.

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

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

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

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

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

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

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2]

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

Function Name:	lambda_ptx_CO2
Subprogram with value of the function:	REAL*8 FUNCTION LAMPTCO2(P,T,X)
for call from Fortran	REAL*8 P,T,X
Subprogram with parameter:	INTEGER*4 FUNCTION C_LAMPTXCO2(LAM,P,T,X)
for call from the DLL	REAL*8 LAM,P,T,X

Input Values

P – Pressure p in bar

T - Temperature t in °C

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

Result

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

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

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

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

Details on the phase fraction x

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

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

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

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

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

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

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

Boiling and dew curve: Temperature range from t_t to t_c

Pressure range from p_t to p_c

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

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

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

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

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

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

Pressure range from p_t to p_{\max_ice}

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

Pressure range from p_t to p_{\max}

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

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

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

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

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

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

Sublimation and

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

Pressure range from p_{\min} to p_t

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2], [3]

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

Function Name: **ny_ptx_CO2**

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

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

Input Values

P – Pressure p in bar

T - Temperature t in °C

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

Result

NYPTXCO2, NY or ny_ptx_CO2 – Kinematic viscosity $\nu = \eta * v$ in m²/s

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

Temperature range: from t_l 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_l to t_c

Pressure range from p_l 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_l to t_{max_ice}

Pressure range from p_l to p_{max_ice}

Solidification curve: Temperature range from t_l to t_{max}

Pressure range from p_l to p_{max}

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

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

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

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

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2], [3]

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

Function Name:	pmel_t_CO2
Subprogram with value of the function:	REAL*8 FUNCTION PMELCO2(T)
for call from Fortran	REAL*8 T
Subprogram with parameter:	INTEGER*4 FUNCTION C_PMELCO2(PMEL,T)
for call from the DLL	REAL*8 PMEL,P,T,X

Input Values

T - Temperature t in °C

Result

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

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

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

References: [2]

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

Function Name: **psub_t_CO2**

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

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

Input Values

T - Temperature t in °C

Result

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

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

Temperature range: from t_{\min} to t_c

Results for wrong input values

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

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

References: [2]

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

Function Name: **Pr_ptx_CO2**

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

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

Input Values

P – Pressure p in bar

T - Temperature t in °C

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

Result

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

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

Temperature range: from t_l 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. Ig 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_l to t_c

Pressure range from p_l 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_l to t_{max_ice}

Pressure range from p_l to p_{max_ice}

Solidification curve: Temperature range from t_l to t_{max}

Pressure range from p_l 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 $\text{PRPTXCO2} = -1000$, $\text{PR} = -1000$ or $\text{Pr}_{\text{ptx_CO2}} = -1000$ for input values:

Single phase region:

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

- at $p < p_{\min}$ or $p > p_{\max}$
- at $t < t_l$ 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 $t < t_l$ or $t > t_c$
- at $t = -1000$ and $p < p_t$ or $p > p_c$
- at $p < p_t$ or $p > p_c$
- at $t < t_l$ 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 $t < t_l$ 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 $t < t_l$ or $t > t_{\max}$ or $t > t_{\max_ice}$ at $x = 10$

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

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

References: [2], [3]

Vapor Pressure $p_s = f(t)$

Function Name:	ps_t_CO2
Subprogram with value of the function:	REAL*8 FUNCTION PSTCO2(T)
for call from Fortran	REAL*8 T
Subprogram with parameter:	INTEGER*4 FUNCTION C_PSTCO2(PS,T)
for call from the DLL	REAL*8 PS,T

Input Values

T - Temperature t in °C

Result

PSTCO2, PS or ps_t_CO2 – Vapor pressure p_s in bar

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

Temperature range: from t_l to t_c

Results for wrong input values

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

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

References: [2]

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

Function Name:	rho_ptx_CO2
Subprogram with value of the function:	REAL*8 FUNCTION ROPTXCO2(P,T,X)
for call from Fortran	REAL*8 P,T,X
Subprogram with parameter:	INTEGER*4 FUNCTION C_ROPTXCO2(RHO,P,T,X)
for call from the DLL	REAL*8 RHO,P,T,X

Input Values

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

Result

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

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

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

Details on the phase fraction x

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

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

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

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

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

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

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

Boiling and dew curve: Temperature range from t_l to t_c
 Pressure range from p_l 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_l to t_{\max_ice}
 Pressure range from p_l 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: [2]

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

Function Name:	s_ptx_CO2
Subprogram with value of the function:	REAL*8 FUNCTION SPTXCO2(P,T,X)
for call from Fortran	REAL*8 P,T,X
Subprogram with parameter:	INTEGER*4 FUNCTION C_SPTXCO2(S,P,T,X)
for call from the DLL	REAL*8 S,P,T,X

Input Values

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

Result

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

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

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

Details on the phase fraction x

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2]

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

Function Name:	t_ph_CO2
Subprogram with value of the function:	REAL*8 FUNCTION TPHCO2(P,H)
for call from Fortran	REAL*8 P,H
Subprogram with parameter:	INTEGER*4 FUNCTION C_TPHCO2(T,P,H)
for call from the DLL	REAL*8 T,P,H

Input Values

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

Result

TPHCO2, T or t_ph_CO2 – Temperature t in °C

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

Pressure range: from p_{\min} to p_{\max} for liquid and steam
 from p_{\min} to p_{\max_ice} for solid
 Enthalpy range: from $h < h_{\max} = h(p_{\min}, t_{\max})$ to $h > h_{\min} = h(p_{\min}, t_{\min})$
 Temperature range: from t_{\min} to t_{\max} (resulting from internal calculation of the subprograms)

Details on calculating the two phase regions

Using the given values for p and h , the program determines whether the point of state to be calculated is located in the single phase region (solid, liquid or steam) or in the two phase region. The two phase regions wet steam region, melting region and sublimation region (cp. Ig 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 $t < t_l$ 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 $t < t_l$ 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 $t > t_l$

References: [2]

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

Function Name: **t_ps_CO2**

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

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

Input Values

P – Pressure p in bar

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

Result

TPSCO2, T or t_ps_CO2 – Temperature t in °C

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

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

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

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

Details on calculating the two phase regions

Using the given values for p and h , the program determines whether the point of state to be calculated is located in the single phase region (solid, liquid or steam) or in the two phase region. The two phase regions wet steam region, melting region and sublimation region (cp. Ig 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 $t < t_l$ 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 $t < t_l$ 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 $t > t_l$

References: [2]

Saturation Temperature $t_s = f(p)$

Function Name:	ts_p_CO2
Subprogram with value of the function:	REAL*8 FUNCTION TSPCO2(P)
for call from Fortran	REAL*8 P
Subprogram with parameter:	INTEGER*4 FUNCTION C_TSPCO2(TS,P)
for call from the DLL	REAL*8 TS,P

Input Values

P – Pressure p in bar

Result

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

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

Pressure range: from p_t to p_c

Results for wrong input values

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

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

References: [2]

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

Function Name: **tmel_p_CO2**

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

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

Input Values

P – Pressure p in bar

Result

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

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

Pressure range: from p_t to p_{max}

Results for wrong input values

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

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

References: [2]

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

Function Name: **tsub_p_CO2**

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

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

Input Values

P – Pressure p in bar

Result

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

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

Pressure range: from p_{\min} to p_t

Results for wrong input values

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

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

References: [2]

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

Function Name: **v_ptx_CO2**

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

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

Input Values

P – Pressure p in bar

T - Temperature t in °C

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

Result

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

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

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

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

Details on the phase fraction x

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

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

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

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

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

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

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

Boiling and dew curve: Temperature range from t_t to t_c

Pressure range from p_t to p_c

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

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

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

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

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

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

Pressure range from p_t to p_{\max_ice}

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

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

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

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

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

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

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

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

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2]

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

Function Name: **w_ptx_CO2**

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

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

Input Values

P – Pressure p in bar

T - Temperature t in °C

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

Result

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

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

Temperature range: from t_t to t_{max}

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

Details on the phase fraction x

If the state point to be calculated is located in the single phase region (liquid or superheated steam), $x = -1$ must be entered as a pro-forma value. Calculating solid is not possible.

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

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

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

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

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

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

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

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

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

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

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

Concerning pressure and temperature either the given value for t and $p = -1000$ or the given value for p and $t = -1000$ and in both cases the value 11 for x must be entered when calculating solidifying liquid.

If p and t and x are entered as given values, the program tests whether p and t fulfil the melting pressure curve.

Melting curve: Temperature range from t_t to t_{max_ice}
Pressure range from p_t to p_{max_ice}

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

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

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

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

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

Results for wrong input values

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

Single phase region:

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

- at $p < p_{\min}$ or $p > p_{\max}$
- at $t < t_l$ 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 $t < t_l$ or $t > t_c$
- at $t = -1000$ and $p < p_t$ or $p > p_c$
- at $p < p_t$ or $p > p_c$
- at $t < t_l$ 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 $t < t_l$ 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 $t < t_l$ or $t > t_{\max}$ or $t > t_{\max_ice}$ at $x = 10$

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

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

References: [2]

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

Function Name: **x_ph_CO2**

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

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

Input Values

P – Pressure p in bar

H - Specific enthalpy h in kJ/kg

Result

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

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

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

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

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

Details on calculating the two phase regions

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

Results for wrong input values

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

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

Two phase regions:

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

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

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

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

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

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

References: [2]

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

Function Name:	x_ps_CO2
Subprogram with value of the function:	REAL*8 FUNCTION XPSCO2(P,S) for call from Fortran REAL*8 P,S
Subprogram with parameter:	INTEGER*4 FUNCTION C_XPSCO2(X,P,S) for call from the DLL REAL*8 X,P,S

Input Values

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

Result

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

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

Pressure range: from p_{\min} to p_{\max} for liquid and steam
 from p_{\min} to p_{\max_ice} for solid
 Entropy range: from $s < s_{\max} = s(p_{\min}, t_{\max})$ to $s > s_{\min} = s(p_{\min}, t_{\min})$
 Temperature range: from t_{\min} to t_{\max} (resulting from internal calculation of the subprograms)

Details on calculating the two phase regions

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

Results for wrong input values

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

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

Two phase regions:

- Wet steam region ($0 \leq x \leq 1$):
- at $p < p_t$ or $p > p_c$
- at calculation result $t < t_t$ or $t > t_c$

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

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

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

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

References: [2]

3.3 Property Functions for Solid Carbon Dioxide (Dry Ice)

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

Function Name: **aiCE_pt_CO2**

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

Subprogram with parameter:
INTEGER*4 FUNCTION C_AICEPTCO2(A,P,T)
for call from the DLL
REAL*8 A,P,T

Input Values

P - Pressure p in bar

T - Temperature t in °C

Result

AICEPTCO2, a or aiCE_pt_CO2 – Thermal diffusivity $a = \frac{\lambda * v}{c_p}$ in m^2/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 **aiCE_pt_CO2 = -1000** for input values:

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

References: [4], [5]

```
# FUNC_300
$ a = f(t)
^K a = f(t)
+SUCH:300
```

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

Function Name: **cpICE_pt_CO2**

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

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

Input Values

P - Pressure p in bar

T - Temperature t in °C

Result

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

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

Pressure range: from p_{\min} to p_{\max_ice}

Temperature range: from t_{\min} to t_{\max_ice}

Results for wrong input values

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

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

References: [4]

```
# FUNC_310
$ cpICE = f(t)
^K cpICE = f(t)
+SUCH:310
```

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

Function Name:	hICE_pt_CO2
Subprogram with value of the function:	REAL*8 FUNCTION HICEPTCO2(P,T)
for call from Fortran	REAL*8 P,T
Subprogram with parameter:	INTEGER*4 FUNCTION C_HICEPTCO2(H,P,T)
for call from the DLL	REAL*8 H,P,T

Input Values

P - Pressure p in bar

T - Temperature t in °C

Result

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

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

Pressure range: from p_{\min} to p_{\max_ice}

Temperature range: from t_{\min} to t_{\max_ice}

Results for wrong input values

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

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

References: [4]

```
# FUNC_320
$ hICE = f(t)
^ hICE = f(t)
+ SUCH:320
```

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

Function Name:	lambdaICE_t_CO2
Subprogram with value of the function: for call from Fortran	REAL*8 FUNCTION LAMICETCO2(T) REAL*8 T
Subprogram with parameter: for call from the DLL	INTEGER*4 FUNCTION C_LAMICETCO2(LAM,T) REAL*8 LAM,T

Input Values

T - Temperature t in °C

Result

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

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

Temperature range: from t_{\min} to t_{\max_ice}

Results for wrong input values

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

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

References: [5]

```
# FUNC_330
$ lambdaICE = f(t)
^K lambdaICE = f(t)
+SUCH:330
```

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

Function Name:	rholCE_pt_CO2
Subprogram with value of the function: for call from Fortran	REAL*8 FUNCTION RHOICEPTCO2(P,T) REAL*8 P,T
Subprogram with parameter: for call from the DLL	INTEGER*4 FUNCTION C_RHOICEPTCO2(RHO,P,T) REAL*8 RHO,P,T

Input Values

P - Pressure p in bar

T - Temperature t in °C

Result

RHOICEPTCO2, RHO or rholCE_pt_CO2 - Density ρ in kg/m³

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

Pressure range: from p_{\min} to p_{\max_ice}

Temperature range: from t_{\min} to t_{\max_ice}

Results for wrong input values

Result **RHOICEPTCO2 = -1000, RHO = -1000** or **rholCE_pt_CO2 = -1000** for input values:

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

References: [4]

```
# FUNC_340
$ rholCE = f(t)
^ rholCE = f(t)
+ SUCH:340
```

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

Function Name:	sICE_pt_CO2
Subprogram with value of the function:	REAL*8 FUNCTION SICEPTCO2(P,T)
for call from Fortran	REAL*8 P,T
Subprogram with parameter:	INTEGER*4 FUNCTION C_SICEPTCO2(S,P,T)
for call from the DLL	REAL*8 S,P,T

Input Values

P - Pressure p in bar

T - Temperature t in °C

Result

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

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

Pressure range: from p_{\min} to p_{\max_ice}

Temperature range: from t_{\min} to t_{\max_ice}

Results for wrong input values

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

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

References: [4]

```
# FUNC_350
$ sICE = f(t)
^K sICE = f(t)
+ SUCH:350
```

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

Function Name:	vlCE_pt_CO2
Subprogram with value of the function:	REAL*8 FUNCTION VICEPTCO2(P,T)
for call from Fortran	REAL*8 P,T
Subprogram with parameter:	INTEGER*4 FUNCTION C_VICETCO2(V,P,T)
for call from the DLL	REAL*8 V,P,T

Input Values

P - Pressure p in bar

T - Temperature t in °C

Result

VICEPTCO2, V or vlCE_pt_CO2 – specific volume v in m³/kg

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

Pressure range: from p_{\min} to p_{\max_ice}

Temperature range: from t_{\min} to t_{\max_ice}

Results for wrong input values

Result **VICEPTCO2 = -1000, V = -1000** or **vlCE_pt_CO2 = -1000** for input values:

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

References: [4]

```
# FUNC_360
$ vICE = f(t)
^K vICE = f(t)
+ SUCH:360
```

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

Function Name:	tICE_ph_CO2
Subprogram with value of the function:	REAL*8 FUNCTION TICEPHCO2(P,H)
for call from Fortran	REAL*8 P,H
Subprogram with parameter:	INTEGER*4 FUNCTION C_TICEPHCO2(T,P,H)
for call from the DLL	REAL*8 T,P,H

Input Values

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

Result

TICEPHCO2, T or tICE_ph_CO2 - Temperature in °C

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

- Enthalpy range: from $h > h_{\min} = h(t_{\min})$ to $h < h_{\max_ice} = h(t_{\max_ice})$
- Pressure range: from p_{\min} to p_{\max_ice}
- Temperature range: for results from t_{\min} to t_{\max_ice}

Results for wrong input values

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

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

References: [4]

```
# FUNC_370
$ tICE = f(h)
 $\wedge$  tICE = f(h)
+ SUCH:370
```

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

Function Name:	tICE_ps_CO2
Subprogram with value of the function:	REAL*8 FUNCTION TICEPSCO2(P,S)
for call from Fortran	REAL*8 P,S
Subprogram with parameter:	INTEGER*4 FUNCTION C_TICEPSCO2(T,P,S)
for call from the DLL	REAL*8 T,P,S

Input Value

- P** - Pressure p in bar
S – Specific Entropy in kJ/(kg K)

Result

TICEPSCO2, T or tICE_ps_CO2 - Temperature in °C

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

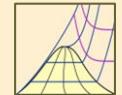
- Entropy range: from $s > s_{\min} = s(t_{\min})$ to $s < s_{\max_ice} = s(t_{\max_ice})$
Pressure range: from p_{\min} to p_{\max_ice}
Temperature range: for results from t_{\min} to t_{\max_ice}

Results for wrong input values

- Result **TICEPSCO2 = -1000, T = -1000** or **tICE_ps_CO2 = -1000** for input values:
- at $s < s_{\min} = s(t_{\min})$ or $s > s_{\max_ice} = s(t_{\max_ice})$
- at $p < p_{\min}$ or $p > p_{\max_ice}$

References: [4]

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



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

Water and Steam

Library LibIF97

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

Library LibSBTL_IF97

Library LibSBTL_95

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

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:
 CO_2 - Span, Wagner H_2O - IAPWS-95
 O_2 - Schmidt, Wagner N_2 - Span et al.
Ar - Tegeler et al.
and of the ideal gases:
 SO_2 , CO , Ne
(Scientific Formulation of Bücker et al.)

Consideration of:

- Dissociation from VDI 4670
- Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:

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

Consideration of:

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

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

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

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Humid Air

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

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
CH_3OH	Methanol
$\text{C}_3\text{H}_8\text{O}_3$	Glycerol
K_2CO_3	Potassium carbonate
CaCl_2	Calcium chloride
MgCl_2	Magnesium chloride
NaCl	Sodium chloride
$\text{C}_2\text{H}_3\text{KO}_2$	Potassium acetate
CHKO_2	Potassium formate
LiCl	Lithium chloride
NH_3	Ammonia

Formulation of the International Institute of Refrigeration (IIR 2010)

Ethanol**Library LibC2H5OH**Formulation of
Schroeder (2012)**Methanol****Library LibCH3OH**Formulation of
de Reuck and Craven (1993)**Propane****Library LibPropane**Formulation of
Lemmon et al. (2009)**Siloxanes as ORC Working Fluids**Octamethylcyclotetrasiloxane $C_8H_{24}O_4Si_4$ **Library LibD4**Decamethylcyclopentasiloxane $C_{10}H_{30}O_5Si_5$ **Library LibD5**Tetradecamethylhexasiloxane $C_{14}H_{42}O_5Si_6$ **Library LibMD4M**Hexamethyldisiloxane $C_6H_{18}OSi_2$ **Library LibMM**

Formulation of Colonna et al. (2006)

Dodecamethylcyclohexasiloxane $C_{12}H_{36}O_6Si_6$ **Library LibD6**Decamethyltetrasiloxane $C_{10}H_{30}O_3Si_4$ **Library LibMD2M**Dodecamethylpentasiloxane $C_{12}H_{36}O_4Si_5$ **Library LibMD3M**Octamethyltrisiloxane $C_8H_{24}O_2Si_3$ **Library LibMDM**

Formulation of Colonna et al. (2008)

Nitrogen and Oxygen**Libraries****LibN2 and LibO2**Formulations of Span et al. (2000)
and Schmidt and Wagner (1985)**Hydrogen****Library LibH2**Formulation of
Leachman et al. (2009)**Helium****Library LibHe**Formulation of
Arp et al. (1998)**Hydrocarbons**

- Decane $C_{10}H_{22}$ **Library LibC10H22**
- Isopentane C_5H_{12} **Library LibC5H12_ISO**
- Neopentane C_5H_{12} **Library LibC5H12_NEO**
- Isohexane C_6H_{14} **Library LibC6H14**
- Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

- Carbon monoxide CO **Library LibCO**
- Carbonyl sulfide COS **Library LibCOS**
- Hydrogen sulfide H_2S **Library LibH2S**
- Nitrous oxide N_2O **Library LibN2O**
- Sulfur dioxide SO_2 **Library LibSO2**
- Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

For more information please contact:KCE-ThermoFluidProperties UG (limited liability) & Co. KG
Professor Hans-Joachim KretzschmarWallotstr. 3
01307 Dresden, GermanyInternet: www.thermofluidprop.com
E-mail: info@thermofluidprop.com
Phone: +49-351-27597860
Mobile: +49-172-7914607
Fax: +49-3222-4262250**The following thermodynamic and transport properties can be calculated^a:****Thermodynamic Properties**

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

Transport Properties

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

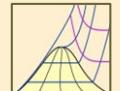
Backward Functions

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

Thermodynamic Derivatives

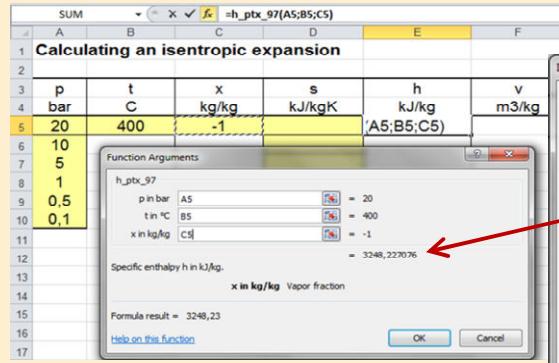
- Partial derivatives can be calculated.

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

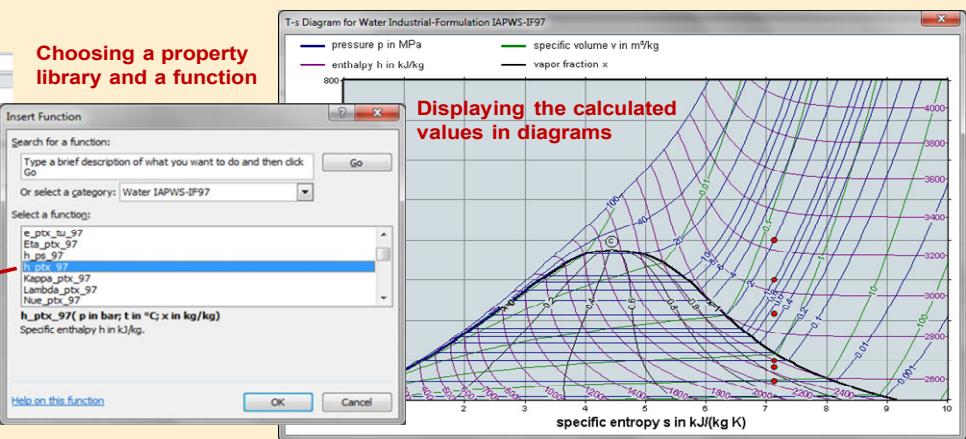


Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Add-In FluidEXL^{Graphics} for Excel®



Menu for the input of given property values

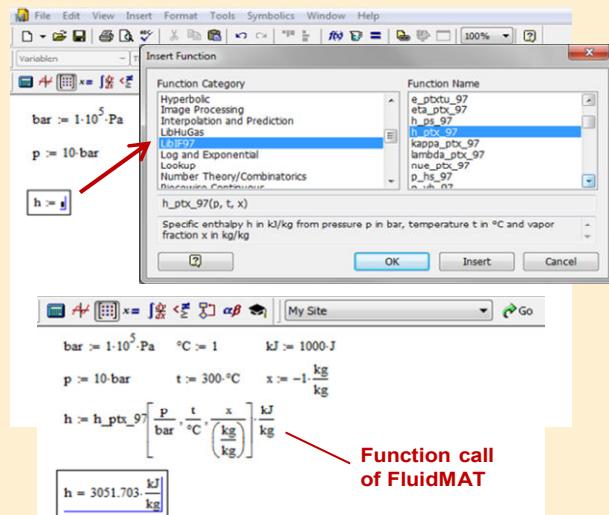


Choosing a property library and a function

Displaying the calculated values in diagrams

Add-In FluidMAT for Mathcad®

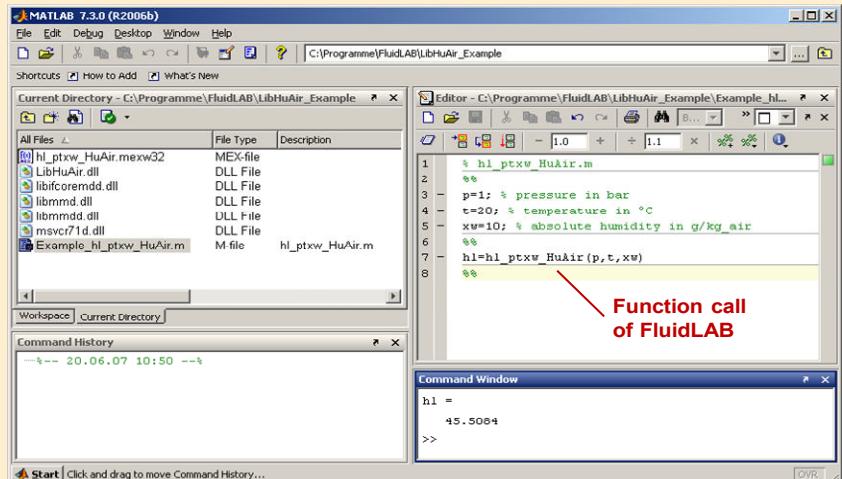
The property libraries can be used in Mathcad®.



Function call of FluidMAT



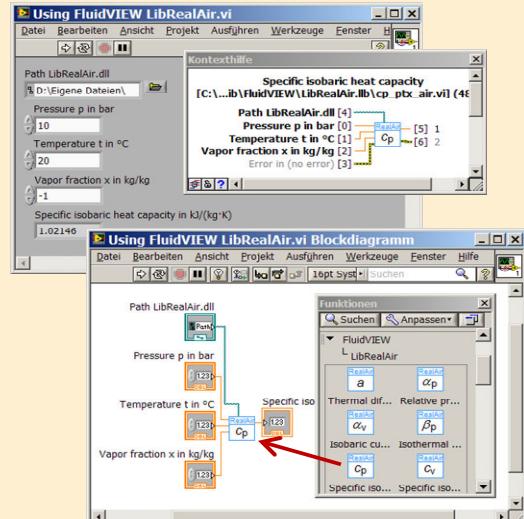
Using the Add-In FluidLAB the property functions can be called in MATLAB®.



Function call of FluidLAB

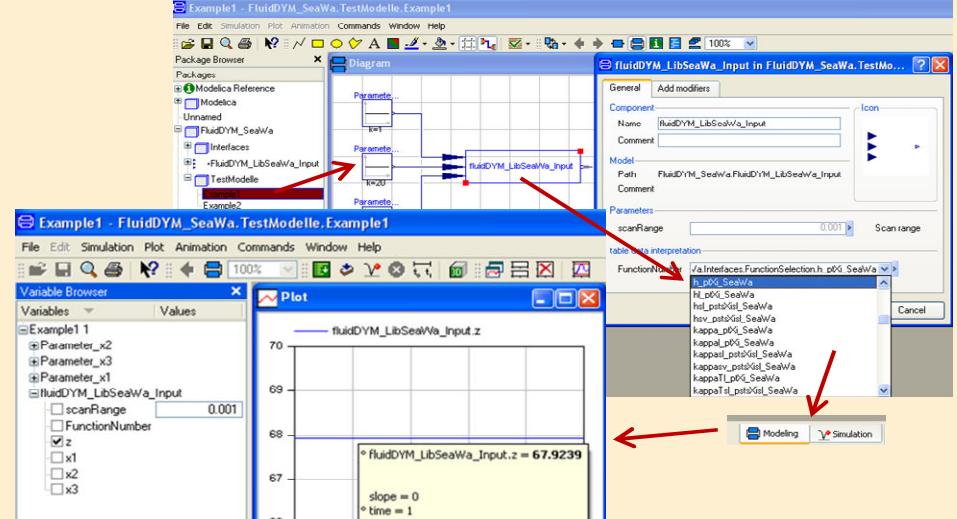
Add-On FluidVIEW for LabVIEW™

The property functions can be calculated in LabVIEW™.

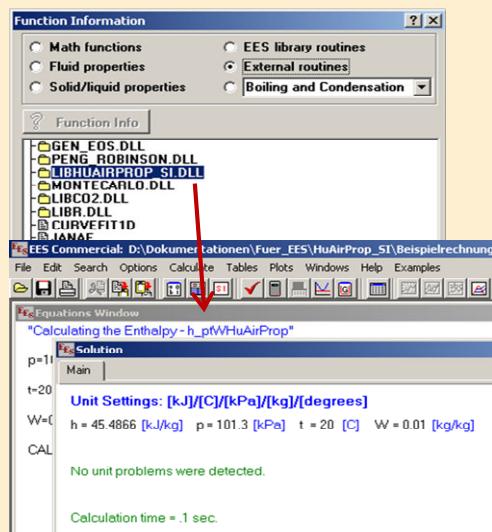


Add-In FluidDYM for DYMOLA® (Modelica) and SimulationX®

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



Add-In FluidEES for Engineering Equation Solver®



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

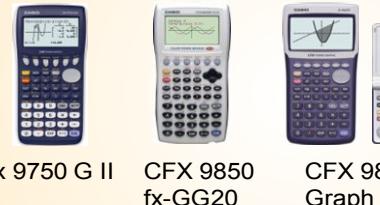


Online Property Calculator at www.thermofluidprop.com

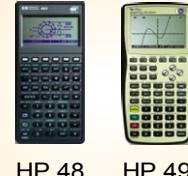
This screenshot shows the 'Zittau's Fluid Property Calculator' web application. It has a header for 'Fluid: Water and Steam IAPWS-IF97 - LibIF97', 'Function: Specific enthalpy h(p,t,x)', and 'Unit System: SI'. Below this is a section for 'Enter given values: Range of validity' with fields for Pressure p (100 bar), Temperature t (400 °C), and Vapor fraction x (-1 kg/kg). There's also a 'Calculate / Recalculate' button. To the right, there's a graph of steam properties and some descriptive text about the software's availability across various engineering tools.

Property Software for Pocket Calculators

FluidCasio



FluidHP



FluidTI



For more information please contact:

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

5. References

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- [5] Kuprianoff, J.:
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6. Satisfied Customers

Date: 07/2019

The following companies and institutions use the property libraries:

- FluidEXL^{Graphics} for Excel®
- FluidLAB for MATLAB® and Simulink
- FluidMAT for Mathcad®
- FluidPRIME for Mathcad Prime®
- FluidEES for Engineering Equation Solver® EES
- FluidDYM for Dymola® (Modelica) and SimulationX®
- FluidVIEW for LabVIEW™
- DLLs for Windows™
- Shared Objects for Linux®.

2019

WARNICA, Waterloo, Canada	07/2019
MIBRAG, Zeitz	06/2019
Pöry, Zürich, Switzerland	06/2019
RWTH Aachen, Inst. Strahlantriebe und Turbomaschinen	06/2019
Midiplan, Bietigheim-Bissingen	06/2019
GKS Schweinfurt	06/2019
HS Zittau/Görlitz, Wirtschaftswissenschaften und Wirtschaftsingenieurwesen	06/2019
ILK Dresden	06/2019
HZDR Helmholtz Zentrum Dresden-Rossendorf	06/2019
TH Köln, TGA	05/2019
IB Knittel, Braunschweig	05/2019
Norsk Energi, Oslo, Norway	05/2019
STEAG Essen	05/2019
Stora Enso, Eilenburg	05/2019
IB Lücke, Paderborn	05/2019
Haarslev, Sonderso, Denmark	05/2019
MAN Augsburg	05/2019
Wieland Werke, Ulm	04/2019
Fels-Werke, Elbingerode	04/2019
Univ. Luxembourg Luxembourg	04/2019
BTU Cottbus, Power Engineering	03/2009
Eins-Energie Sachsen, Schwarzenberg	03/2019
TU Dresden, Kälte- und Kryotechnik	03/2019
ITER, St. Paul Lez Durance Cedex, France	03/2019
Fraunhofer UMSICHT, Oberhausen	03/2019
Comparex Leipzig for Spedition Thiele HEMMERSBACH	03/2019
Rückert NaturGas, Lauf/Pegnitz	03/2019
BASF, Basel, Switzerland	02/2019
Stadtwerke Leipzig	02/2019

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

2018

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

2017

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

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

2016

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

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

2015

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

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GKS, Schweinfurt	03/2014
Technical University of Nuremberg	03/2014
EP-E, Niederstetten	03/2014
Rückert NatUrgas GmbH, Lauf	03/2014
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ZAB, Dessau	02/2014
KIT-TVT, Karlsruhe	02/2014
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STEAG, Herne	11/2013, 12/2013
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TIG-Group, Husum	08/2013
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		11/2013
VGB, Essen		07/2013, 11/2013
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Oschatz GmbH, Essen		01/2013
frischli Milchwerke, Rehburg-Loccum		01/2013

2012

Voith, Bayreuth	12/2012
Technical University of Munich	12/2012
Dillinger Huette	12/2012
University of Stuttgart	11/2012
Siemens, Muehlheim	11/2012
Sennheiser, Hannover	11/2012
Oschatz GmbH, Essen	10/2012
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University of Duisburg	10/2012

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Pöyry Deutschland GmbH, Dresden	08/2012
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Meyer Werft, Papenburg	07/2012
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Nikon Research of America, Belmont, USA	06/2012
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PEU, Espenheim	05/2012
Luzern University of Applied Sciences, Switzerland	05/2012
BASF, Ludwigshafen (general license) via Fichtner IT Consult	05/2012
SPX Balcke-Dürr, Ratingen	05/2012, 07/2012
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Vattenfall, Berlin	04/2012
ALSTOM, Baden	04/2012
SKW, Piesteritz	04/2012
TERA Ingegneria, Trento, Italy	04/2012
Siemens, Erlangen	04/2012, 05/2012
LAWI Power, Dresden	04/2012
Stadtwerke Leipzig	04/2012
SEITZ, Wetzikon, Switzerland	03/2012, 07/2012
M & M, Bielefeld	03/2012
Sennheiser, Wedemark	03/2012
SPG, Montreuil Cedex, France	02/2012
German Destilation, Sprendlingen	02/2012
Lopez, Munguia, Spain	02/2012
Endress & Hauser, Hannover	02/2012
Palo Alto Research Center, USA	02/2012
WIPAK, Walsrode	02/2012
Freudenberg, Weinheim	01/2012
Fichtner, Stuttgart	01/2012
airinotec, Bayreuth	01/2012, 07/2012
University Auckland, New Zealand	01/2012
VPC, Vetschau	01/2012
Franken Guss, Kitzingen	01/2012

2011

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

ILK Dresden	01/2011
Technical University of Dresden	01/2011, 05/2011
	06/2011, 08/2011

2010

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

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

2009

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

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

2008

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

2007

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

2006

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

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

2005

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

Technical University of Dresden, Waste Management	05/2005
Siemens Power Generation, Goerlitz	05/2005
Duesseldorf University of Applied Sciences,	05/2005
Department of Mechanical Engineering and Process Engineering	
Redacom, Nidau, Switzerland	06/2005
Dumas Verfahrenstechnik, Hofheim	06/2005
Alensys Engineering, Erkner	07/2005
Stadtwerke Leipzig	07/2005
SaarEnergie, Saarbruecken	07/2005
ALSTOM ITC, Rugby, Great Britain	08/2005
Technical University of Cottbus, Chair in Power Plant Engineering	08/2005
Vattenfall Europe, Berlin (group license)	08/2005
Technical University of Berlin	10/2005
Basel University of Applied Sciences,	10/2005
Department of Mechanical Engineering, Switzerland	
Midiplan, Bietigheim-Bissingen	11/2005
Technical University of Freiberg, Chair in Hydrogeology	11/2005
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MAN B&W Diesel A/S, Copenhagen, Denmark	02/2004
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Ulm University of Applied Sciences	03/2004
Visteon, Kerpen	03/2004, 10/2004
Technical University of Dresden,	
Professorship of Thermic Energy Machines and Plants	04/2004
Rerum Cognitio, Zwickau	04/2004
University of Saarbruecken	04/2004
Grenzebach BSH, Bad Hersfeld	04/2004
SOFBID Zwingenberg (general EBSILON program license)	04/2004
EnBW Energy Solutions, Stuttgart	05/2004
HEW-Kraftwerk, Tiefstack	06/2004
h s energieanlagen, Freising	07/2004
FCIT, Stuttgart	08/2004
Physikalisch Technische Bundesanstalt (PTB), Braunschweig	08/2004
Mainova Frankfurt	08/2004
Rietschle Energieplaner, Winterthur, Switzerland	08/2004
MAN Turbo Machines, Oberhausen	09/2004
TUEV Sued, Dresden	10/2004
STEAG Kraftwerk, Herne	10/2004, 12/2004
University of Weimar	10/2004
energeticals (e-concept), Munich	11/2004
SorTech, Halle	11/2004

Enertech EUT, Radebeul (company license)	11/2004
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STORA ENSO Sachsen, Eilenburg	12/2004
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Freudenberg Service, Weinheim	12/2004

2003

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

2002

Hamilton Medical AG, Rhaeuens, Switzerland	01/2002
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Stadtwerke Hannover	09/2002
Siemens Power Generation, Goerlitz	10/2002
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Dillinger Huette, Dillingen	11/2002
G.U.N.T. Geraetebau, Barsbuettel	12/2002
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VEAG, Berlin (group license)	12/2002

2001

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KW2 B. V., Amersfoot, Netherlands	01/2001, 11/2001
Eco Design, Saitamaken, Japan	01/2001
M&M Turbine Technology, Bielefeld	01/2001, 09/2001
MVV Energie, Mannheim	02/2001
Technical University of Dresden, Department of Power Machinery and Plants	02/2001
PREUSSAG NOELL, Wuerzburg	03/2001
Fichtner Consulting & IT Stuttgart	04/2001
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Neusiedler AG, Ulmerfeld, Austria	09/2001
h s energieanlagen, Freising	09/2001
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AG KKK - PGW Turbo, Leipzig	01/2000
PREUSSAG NOELL, Wuerzburg	01/2000
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IBR Engineering Reis, Nittendorf-Undorf	02/2000
GK, Hannover	03/2000
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UMAG W. UDE, Husum	03/2000
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Thinius Engineering, Erkrath	04/2000
SaarEnergie, Saarbruecken	05/2000, 08/2000
DVO Data Processing Service, Oberhausen	05/2000
RWTH Aachen University	06/2000
VAUP Process Automation, Landau	08/2000
Knuerr-Lommatec, Lommatsch	09/2000
AVACON, Helmstedt	10/2000
Compania Electrica, Bogota, Colombia	10/2000
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Bayernwerk, Munich	01/1999
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Regensburg University of Applied Sciences	04/1999
Fichtner Consulting & IT, Stuttgart	07/1999
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Technical University of Cottbus, Chair in Power Plant Engineering	07/1999
Technical University of Graz, Department of Thermal Engineering, Austria	11/1999
Ostendorf Engineering, Gummersbach	12/1999

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Fichtner Consulting & IT (CADIS information systems) Stuttgart	05/1998
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B+H Software Engineering Stuttgart	08/1998
Alfa Engineering, Switzerland	09/1998
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SCA Hygiene Products, Munich	10/1998
RWE Energie, Neurath	10/1998
Wilhelmshaven University of Applied Sciences	10/1998
BASF, Ludwigshafen (group license)	11/1998
Energieversorgung, Offenbach	11/1998

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Gerb, Dresden	06/1997
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