

Property Library for Carbon Dioxide

FluidEES with LibCO2 for Engineering Equation Solver®

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Software for the Calculation of the Properties of Carbon Dioxide FluidEES LibCO2

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0 Package Contents

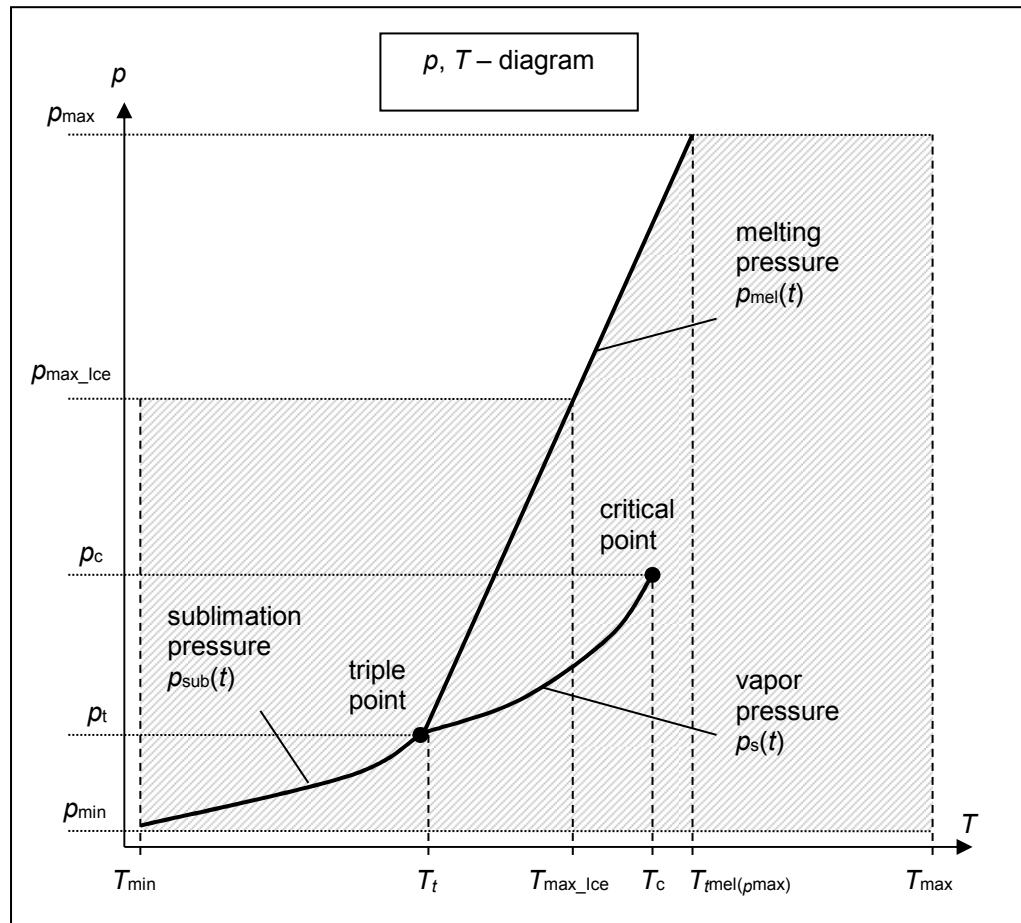
Zip-file "CD_FluidEES_LibCO2.zip" includes the following files:

- FluidEES_LibCO2_Setup.exe - Self-extracting and self-installing program
- LibCO2.dll - DLL with functions of the LibCO2 library
- FluidEES_LibCO2_Docu.pdf - User's Guide
- LibCO2.chm - Help file for the LibCO2 property library

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	APTXXCO2(P,T,X)	C_APTXXCO2(A,P,T,X)	Thermal diffusivity	m ² /s
$c_p = f(p, t, x)$	cp_ptx_CO2	CPPTXXCO2(P,T,X)	C_CPPTXXCO2(CP,P,T,X)	Specific isobaric heat capacity	kJ/(kg K)
$\eta = f(p, t, x)$	eta_ptx_CO2	ETAPTXCO2(P,T,X)	C_ETAPTXCO2(ETA,P,T,X)	Dynamic viscosity	Pa s
$h = f(p, t, x)$	h_ptx_CO2	HPTXXCO2(P,T,X)	C_HPTXXCO2(H,P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p, t, x)$	kappa_ptx_CO2	KAPTXCO2(P,T,X)	C_KAPTXCO2(KAP,P,T,X)	Isentropic exponent	-
$\lambda = f(p, t, x)$	lambda_ptx_CO2	LAMPTCO2(P,T,X)	C_LAMPTXXCO2(LAM,P,T,X)	Thermal conductivity	W/(m K)
$\nu = f(p, t, x)$	ny_ptx_CO2	NYPTXXCO2(P,T,X)	C_NYPTXXCO2(NY,P,T,X)	Kinematic viscosity	m ² /s
$p_{\text{mel}} = f(t)$	pmel_t_CO2	PMELCO2(T)	C_PMELCO2(PMEL,T)	Melting pressure from temperature	bar
$p_{\text{sub}} = f(t)$	psub_t_CO2	PSUBCO2(T)	C_PSUBCO2(PSUB,T)	Sublimation pressure from temperature	bar
$p_s = f(t)$	ps_t_CO2	PSTCO2(T)	C_PSTCO2(PS,T)	Vapor pressure from temperature	bar
$Pr = f(p, t, x)$	Pr_ptx_CO2	PRPTXXCO2(P,T,X)	C_PRPTXXCO2(PR,P,T,X)	Prandtl-Number	-
$\rho = f(p, t, x)$	rho_ptx_CO2	ROPTXXCO2(P,T,X)	C_ROPTXXCO2(RHO,P,T,X)	Density	kg/ m ³
$s = f(p, t, x)$	s_ptx_CO2	SPTXXCO2(P,T,X)	C_SPTXXCO2(S,P,T,X)	Specific entropy	kJ/(kg K)
$t = f(p, h)$	t_ph_CO2	TPHCO2(P,H)	C_TPHCO2(T,P,H)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p, s)$	t_ps_CO2	TPSCO2(P,S)	C_TPSCO2(T,P,S)	Backward function: Temperature from pressure and entropy	°C

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

Property Functions for Solid Carbon Dioxide (Dry Ice)

Functional Dependence	Function Name	Call from Fortran program	Call from the DLL LibCO2 as Parameter	Property or Function	Unit of the Result
$a = f(p, t)$	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_LAMICETCO2 (LAM,T)	Thermal conductivity	W/(m K)
$\rho = f(p, t)$	rhoICE_pt_CO2	RHOICETCO2(P,T)	C_RHOICEPTCO2 (RHO, P, T)	Density	kg/ m³
$s = f(p, t)$	sICE_pt_CO2	SICETCO2(P,T)	C_SICEPTCO2 (S, P, T)	Specific entropy	kJ/ (kg K)

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

Details on the Phase Fraction x

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

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

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

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

In this case it is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. If values for both p and t are entered when calculating wet vapor, the program will consider p and t to be appropriate to represent the vapour pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000 .

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

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

Pressure ranges from $p_t = 5.179618369088$ bar to $p_c = 73.773$ bar

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

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

In this case it is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 10 and 11. If values for both p and t are entered, the program will consider p and t to be appropriate to represent the melting pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000 .

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

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

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

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

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

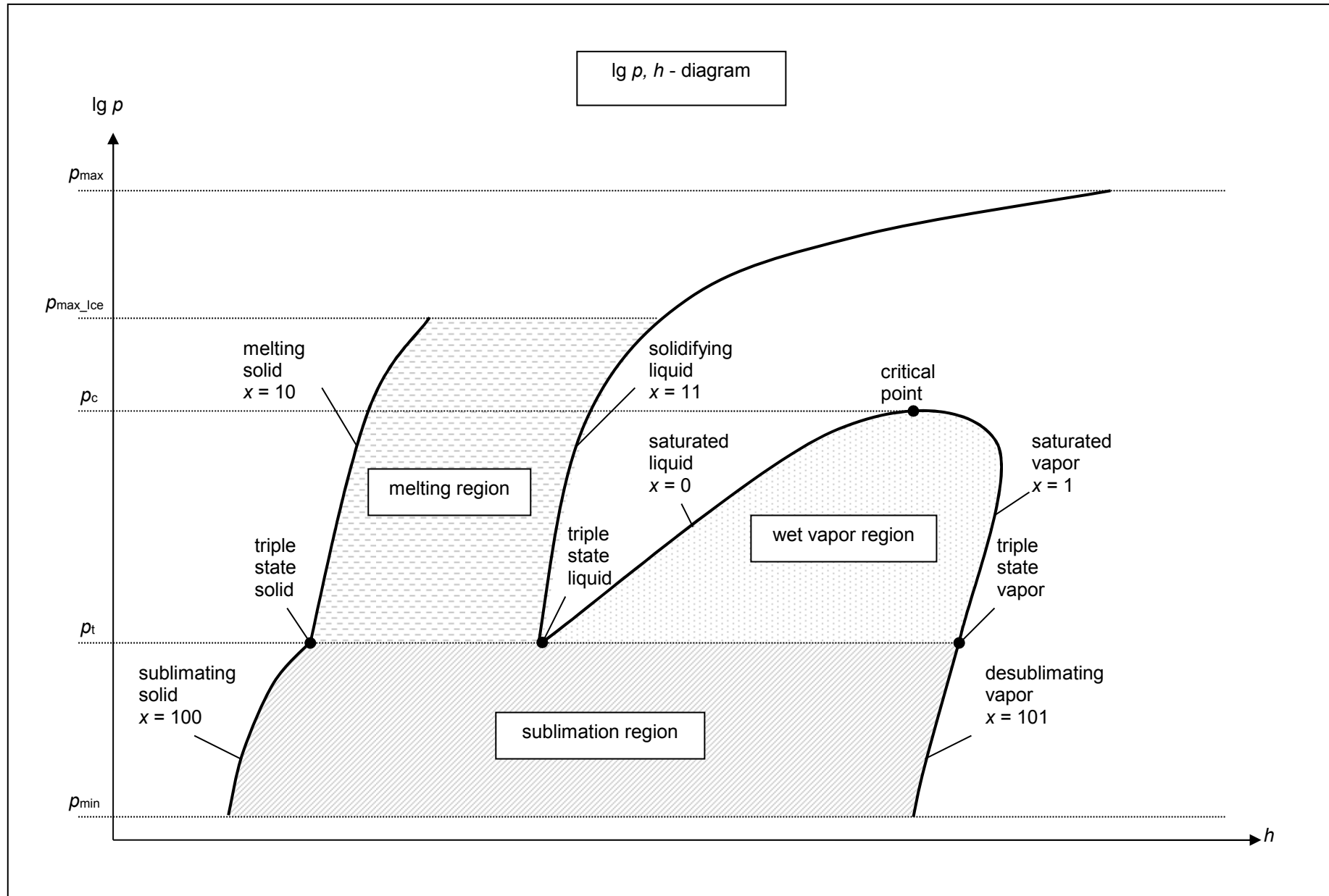
In this case it is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 100 and 101. If values for both p and t are entered, the program will consider p and t to be appropriate to represent the sublimation pressure curve.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

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

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

Note:

If the input values are located outside the range of validity, the calculated function will always result in -1000 . Please find more exact details on every function and its corresponding range of validity in the enclosed software documentation in Chapter 3. The same information may also be accessed via the online help pages.



2 Application of FluidEES in Engineering Equation Solver®

The FluidEES Add-In has been developed to conveniently calculate thermodynamic properties in the Engineering Equation Solver® (EES). It enables, within EES, the direct call of functions relating to carbon dioxide calculated from the LibCO2 property library.

2.1 Installing FluidEES LibCO2

FluidEES is installed by means of a self-extracting setup file.

Before you begin, it is best to close any Windows® applications, since Windows® may need to be rebooted during the installation process and to remove any a FluidEES version which has been delivered before April 2010.

After you have downloaded and extracted the zip-file "CD_FluidEES_LibCO2.zip", you will see the folder

CD_FluidEES_LibCO2

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:

FluidEES_LibCO2_Docu_Eng.pdf

FluidEES_LibCO2_Setup.exe.

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

FluidEES_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.

In the following dialog box, "Destination Location" (see figure below), the default path where Engineering Equation Solver has been installed will be shown (the standard being:

C:\Program Files\EES32\Userlib\LibCO2 (for English version of Windows)

C:\Programme\EES32\Userlib\LibCO2 (for German version of Windows)).

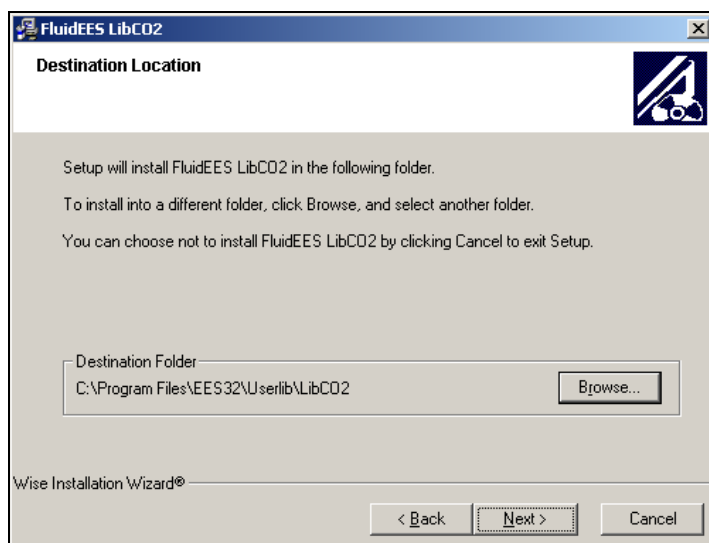


Figure 2.1: Destination Location

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

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

The FluidEES files are now being copied onto your hard disk drive into the "\LibCO2" folder.

Click the "Finish>" button in the following window to finish installation.

The installation program has copied the following files into the directory

C:\Program Files\EES32\Userlib\LibCO2	(for English version of Windows)
C:\Programme\EES32\Userlib\LibCO2	(for German version of Windows)):

advapi32.dll	- Dynamic link library for use in Windows® programs
Dformd.dll	- Dynamic link library for use in Windows® programs
Dforrt.dll	- Dynamic link library for use in Windows® programs
DFORRTD.dll	- Dynamic link library for use in Windows® programs
INSTALL.LOG	- Log file
LC.dll	- Dynamic link library for use in Windows® programs
LibCO2.ctx	- Interface including property functions of LibCO2 for EES®
LibCO2.dll	- Dynamic link library with property functions of LibCO2
LibCO2.chm	- Help file of the LibCO2 property library
msvc60.dll	- Dynamic link library for use in Windows® programs
msvcrt.dll	- Dynamic link library for use in Windows® programs
MSVCRTD.dll	- Dynamic link library for use in Windows® programs
UNWISE.EXE	- File to remove the LibCO2 library
UNWISE.INI	- File belonging to the UNWISE.EXE

Now, you have to overwrite the following files

"LibCO2.dll"

"LibCO2.chm"

"LibCO2.ctx"

in your Engineering Equation Solver directory with the files of the same names provided in your extracted CD_FluidEES_LibCO2 folder.

To do this, open the "CD_FluidEES_LibCO2" folder 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 EES directory (the standard being:

C:\Program Files\EES32\Userlib\LibCO2	(for English version of Windows)
C:\Programme\EES32\Userlib\LibCO2	(for German version of Windows))

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.

Now, you have overwritten the file "LibCO2.dll" successfully.

Repeat these steps in order to copy the other files listed above.

Licensing the LibCO2 Property Library

The licensing procedure has to be carried out when Engineering Equation Solver® starts up and a FluidEES prompt message appears. In this case, you will see the "License Information" window for LibCO2 (see figure below).

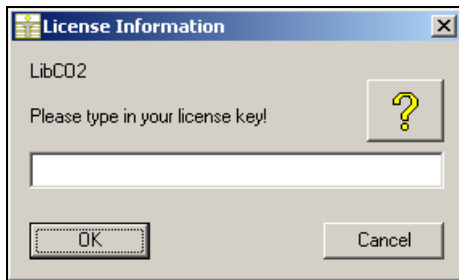


Figure 2.2: "License Information" window

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

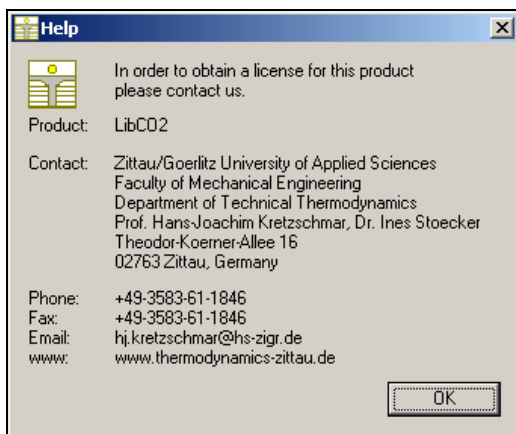


Figure 2.3: "Help" window

If you do not enter a valid license it is still possible to start EES® 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 FluidEES unless you uninstall FluidEES 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.ctx
LibCO2.dll
LibCO2.chm

in the installation folder of FluidEES (the standard being


C:\Program Files\EES32\Userlib\LibCO2 (for English version of Windows)
C:\Programme\EES32\Userlib\LibCO2 (for German version of Windows)).

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

2.2 The FluidEES Help System

As mentioned earlier, FluidEES also provides detailed online help functions.

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

- Click "Options" in the EES menu bar and select "Function Info".
- The "Function Information" window will appear. Select "External routines" and double-click on the entry "LibCO2.DLL".
- A list with calculable functions of the "LibCO2" library appears.
- Find and select the desired function, e.g. "h_ptx_CO2" and click the  button above.

If the "LibCO2.chm" function help cannot be found, confirm the question whether you want to look for it yourself with "Yes." Select the "LibCO2.chm" file in the installation menu of FluidEES in the window which is opened, the standard being

C:\Program Files\EES32\Userlib\LibCO2 (for English version of Windows)
C:\Programme\EES32\Userlib\LibCO2 (for German version of Windows))

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

2.3 Example: Calculation of the Specific Enthalpy $h = f(p, t, x)$ for Carbon Dioxide

Now we will calculate, step by step, the specific enthalpy h as a function of total pressure p , temperature t and vapor fraction x for carbon dioxide, using FluidEES with LibCO2 in the Engineering Equation Solver®.

Please carry out the following instructions:

- Start Engineering Equation Solver (EES).
- The LibCO2 library is loaded by the program automatically.
- It is recommended that you prepare an EES sheet, as shown in Figure 2.4.
 Note: The units of p , t , and x must correspond to those in Chapter 1.

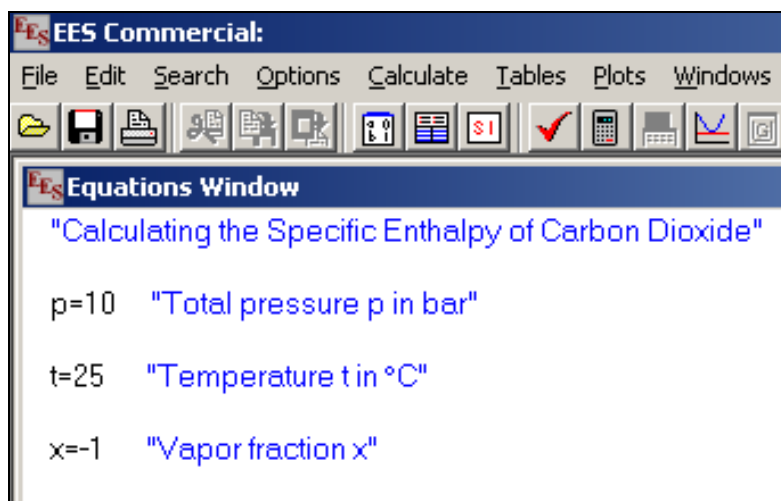


Figure 2.4: Preparing an EES sheet for the calculation

- The values of the function parameters stand for:
 - First operand: Total pressure $p = 10$ bar
 (Range of validity: $p = 2.9081875815 \cdot 10^{-10}$ bar... 8000 bar)
 - Second operand: Temperature $t = 25$ °C
 (Range of validity: $t = t_{\text{mel}} \dots 826.85$ °C)
 - Third operand: Vapor fraction $x = -1$

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 saturated 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: $t_t = -56.558\text{ °C} \dots t_c = 30.9782\text{ °C}$
 $p_t = 5.179618369088\text{ bar} \dots p_c = 73.773\text{ bar}$)

- Confirm your entry by pressing the "ENTER" key.

Note:

If you run Engineering Equation Solver® on an English version of Windows®, the decimal separator will be a dot (as shown in Figure 2.3 and in the following sample calculation). If you run a German version the decimal separator will be a comma. In other words, EES adapts to the language that is set in the "Regional and Language Options" which can be found in the Windows "Control Panel". You can find additional information on this issue by clicking on "Help" in the EES menu bar and then select "Help Index". Click on "Search" in the window which appears, type "decimal separator" and press the "ENTER" key.

- For calculating $h = f(p, t, x)$ you have to call the function "h_ptx_CO2" of the property library LibCO2 as follows:
- Click on "Options" in the EES menu bar and select "Function Info".
- The "Function Information" window will appear. Select "External routines" and you will see the screen shown here in Figure 2.5.

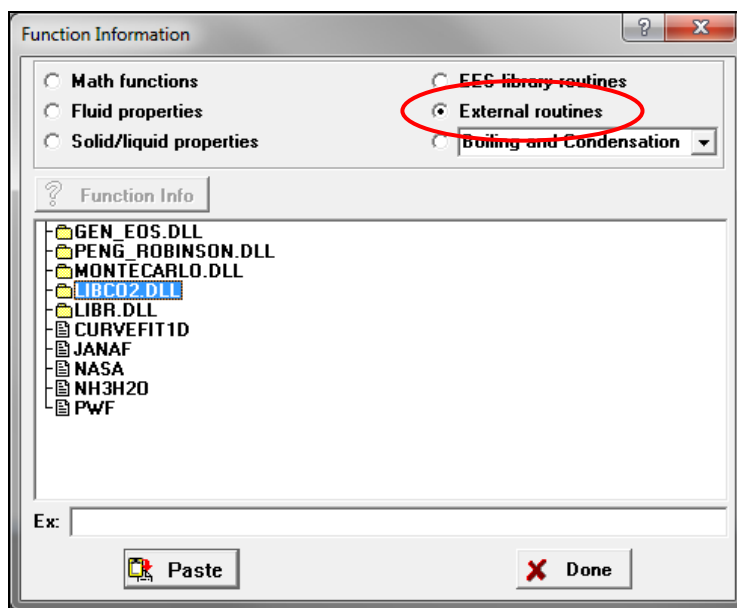


Figure 2.5: "Function Information" window offering different libraries (routines)

- Double-click on the entry "LIBCO2.DLL".
- A list with calculable functions of the "LibCO2" library appears.
- Search and click the "h_ptx_CO2" function (see Figure 2.6) and then click the "Paste" button below.

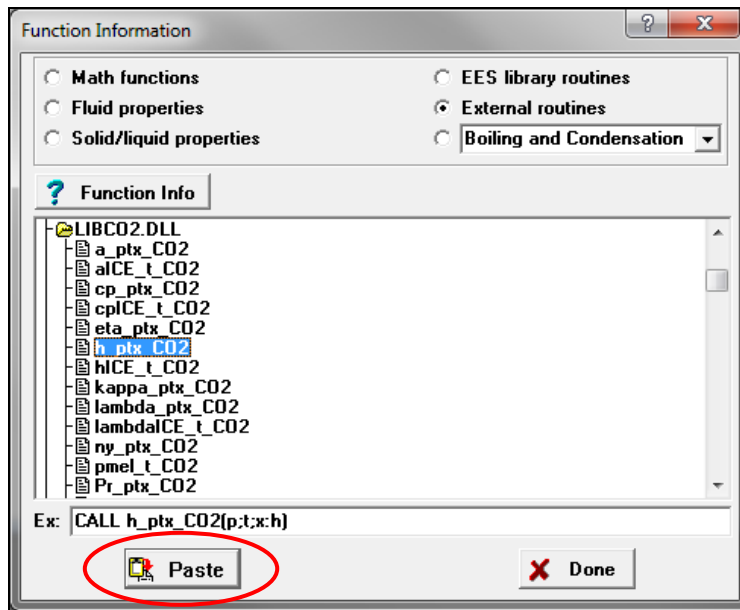


Figure 2.6: Selecting the "h_ptx_CO2" function

- The selected function will be copied and appears in the "Equations Window" (see Figure 2.7).

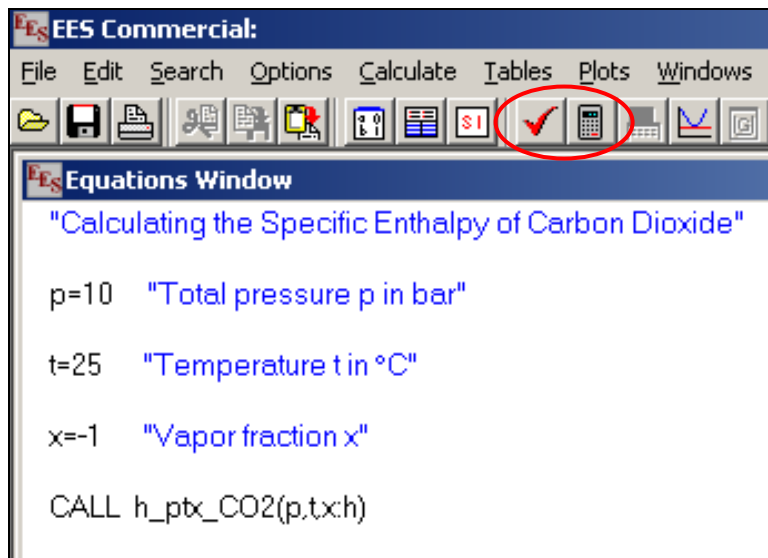




Figure 2.7: "Equations Window" with the call of the property function

- Now, you can check the syntax of the instructions in the "Equations Window" by clicking the  symbol in the upper menu bar of EES. The program tests whether or not the syntax is correct. Confirm the "Information" window which appears by clicking the "OK" button.
- Then click the  symbol in the upper menu bar of EES to start the calculation.
- Soon you will see the "Calculations Completed" window. Leave this window by clicking the "Continue" button.
- The result for the specific enthalpy h appears in the "Solution" window (see Figure 2.8).

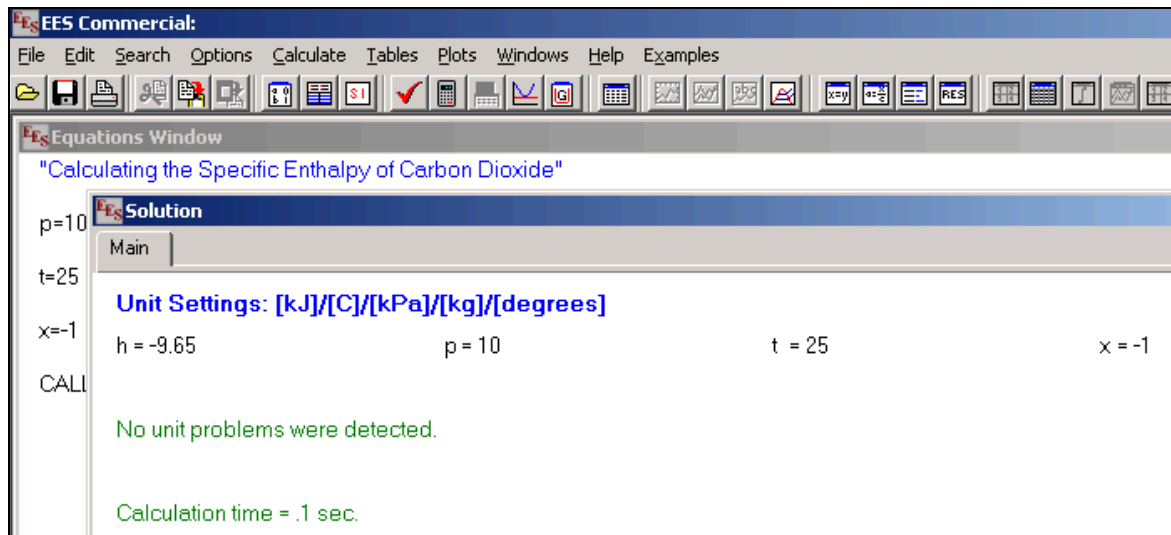


Figure 2.8: "Solution" window showing the result

- You can add units and/or change the number of decimal figures by right-clicking or double-clicking the result or the values of the other variables.
- For our example of the specific enthalpy h , double-click "h = -9.65". The dialog window shown in Figure 2.9 appears.
Select "Fixed decimal" in the dialog window and choose 5 decimals. Then type "kJ/kg" next to "Units:" corresponding to the table of property functions in Chapter 1 and click the "OK" button.

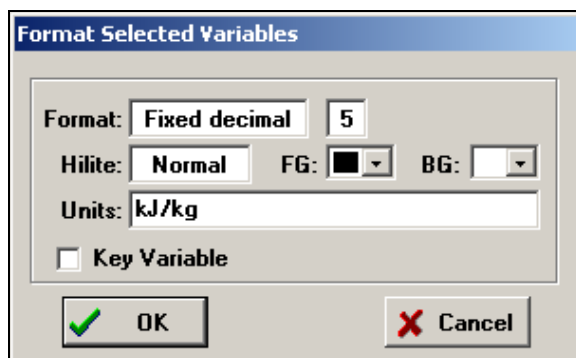


Figure 2.9: Formatting the result

- The same procedure will be done for adding the appropriate units to all variables. Please add the unit bar for the total pressure p , C for °C for the temperature t and kg/kg for the vapor fraction x corresponding to the table of property functions which can be found in Chapter 1.

Note:

You can find additional information on this issue by clicking on "Help" in the EES menu bar and then select "Help Index". Click on "Search" in the window which appears, type "format of variable" and press the "ENTER" key.

- Afterwards, the "Solution" window looks like this (see Figure 2.10):

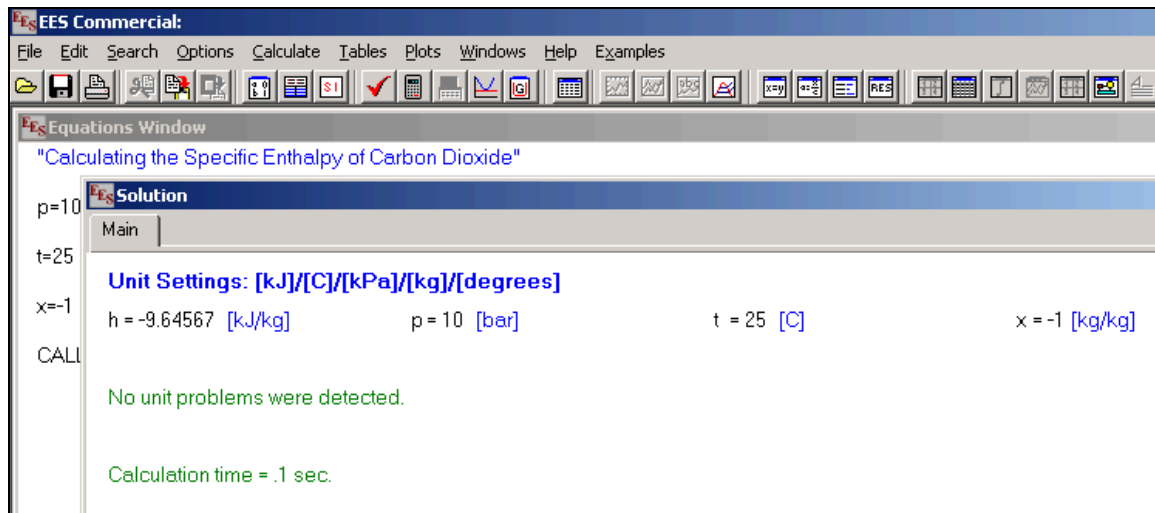


Figure 2.10: "Solution" window with formatted result and variables including units

The calculation of $h = f(p, t, x)$ has thus been carried out.

⇒ The result in our sample calculation here is: " $h = -9.64567$ ". The corresponding unit is kJ/kg (see table of the property functions in Chapter 1).

For further property functions calculable in FluidEES see the function table in Chapter 1.

2.4 Removing FluidEES LibCO2

In order to remove the property library "LibCO2" from your hard disk drive in Windows®, click "Start" in the lower task bar, then "Settings" and "Control Panel".

Afterwards double-click on "Add or Remove Programs".

In the list box of the "Add or Remove Programs" menu which appears, select "FluidEES LibCO2" by clicking on it and click the "Change/Remove" button.

In the following dialog box select "Automatic" and then click the "Next>" button.

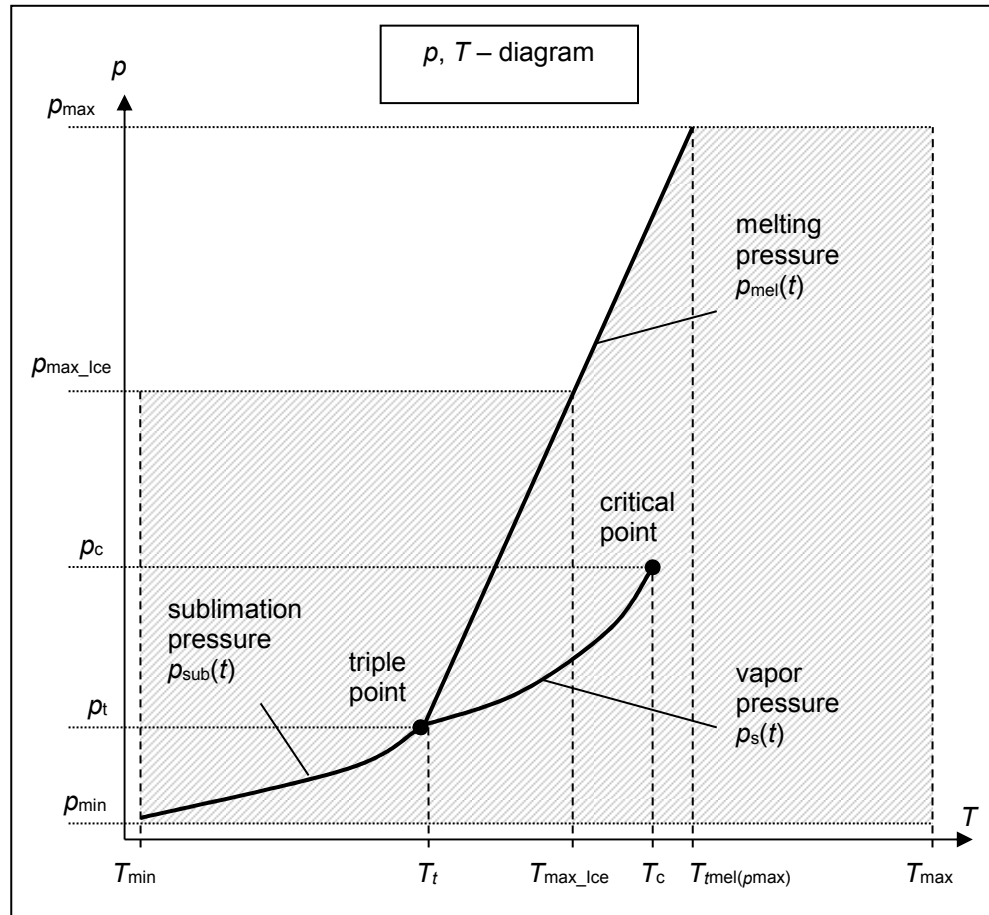
Then confirm the menu "Perform Uninstall" by clicking the "Finish" button.

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

"FluidEES LibCO2" has now been removed.

3. Program Documentation

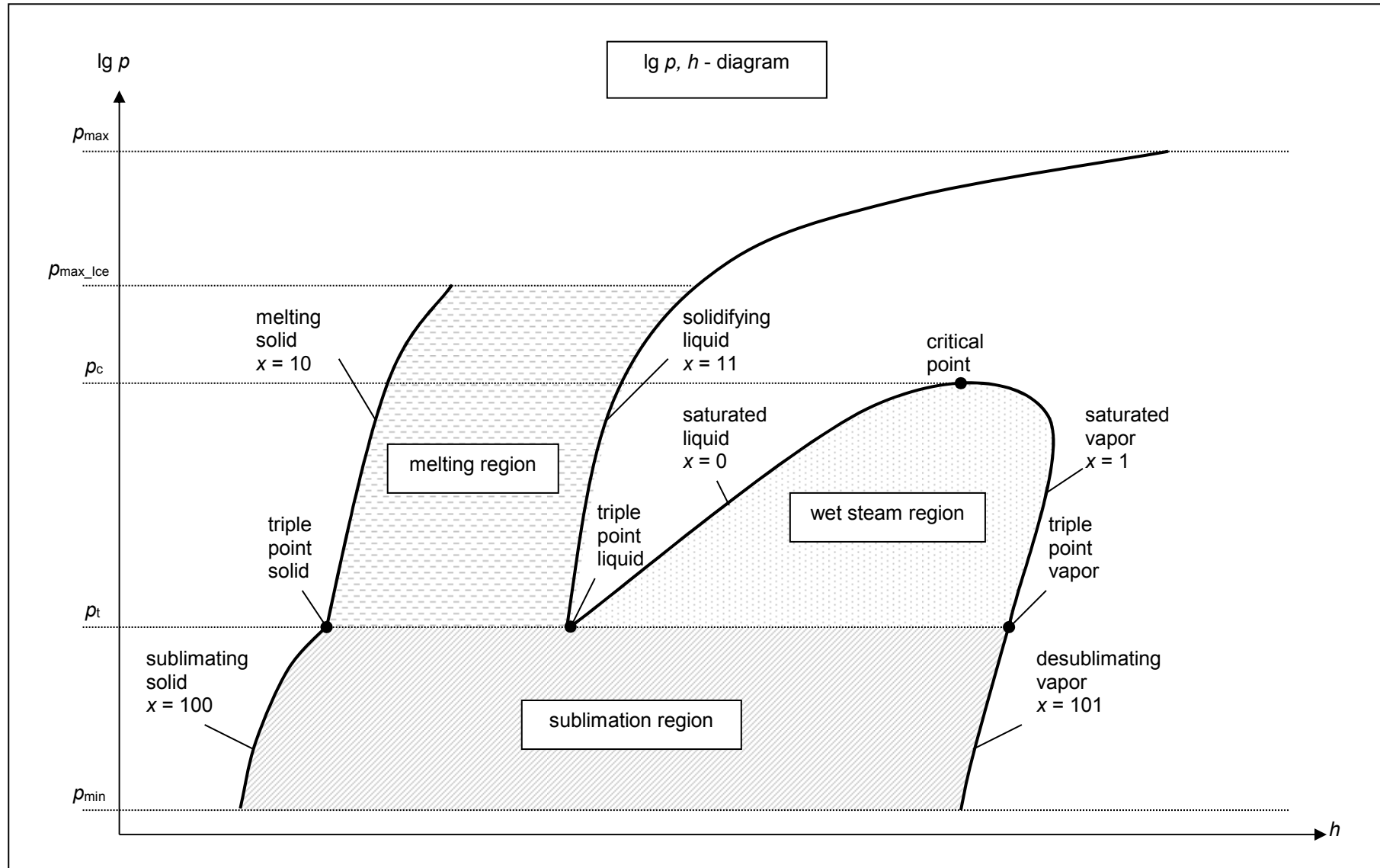
3.1 Ranges of Validity



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



3.2 General Property Functions

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

Function Name: **a_ptx_CO2**

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

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

Input Values

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

Result

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

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

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

Details on the phase fraction x

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

The two phase regions wet steam region, melting region and sublimation region are calculated automatically by the subprograms. For this purpose the following facts have to be considered (cp. 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 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 **APTXXCO2 = -1000, A = -1000** or **a_ptx_CO2 = -1000** for input values:

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2], [3]

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

Function Name: **cp_ptx_CO2**

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

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

Input Values

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

Result

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

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

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

Details on the phase fraction x

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Sublimation and

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

Pressure range from p_{\min} to p_t

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2]

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

Function Name: **eta_ptx_CO2**

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

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

Input Values

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

Result

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

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

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

Details on the phase fraction x

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Results for wrong input values

Result **ETAPTXXCO2 = -1000**, **ETA = -1000** or **eta_ptx_CO2 = -1000** for input values:

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2], [3]

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

Function Name: **h_ptx_CO2**

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

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

Input Values

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

Result

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

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

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

Details on the phase fraction x

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Pressure range from p_t to p_{\max_Ice}

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

Pressure range from p_t to p_{\max}

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

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

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

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

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

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

Sublimation and

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

Pressure range from p_{\min} to p_t

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2]

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

Function Name: **kappa_ptx_CO2**

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

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

Input Values

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

Result

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

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

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

Details on the phase fraction x

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2]

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

Function Name: **lambda_ptx_CO2**

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

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

Input Values

P – Pressure p in bar

T - Temperature t in °C

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

Result

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

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

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

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

Details on the phase fraction x

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

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

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

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

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

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

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

Boiling and dew curve: Temperature range from t_t to t_c

Pressure range from p_t to p_c

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

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

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

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

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

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

Pressure range from p_t to p_{\max_Ice}

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

Pressure range from p_t to p_{\max}

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

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

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

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

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

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

Sublimation and

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

Pressure range from p_{\min} to p_t

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2], [3]

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

Function Name: **ny_ptx_CO2**

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

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

Input Values

P – Pressure p in bar

T - Temperature t in °C

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

Result

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

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

Temperature range: from t_t to t_{\max}

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

Details on the phase fraction x

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

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

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

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

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

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

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

Boiling and dew curve: Temperature range from t_t to t_c

Pressure range from p_t to p_c

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

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

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

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

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

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

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

Pressure range from p_t to p_{\max_Ice}

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

Pressure range from p_t to p_{\max}

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

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

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

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

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2], [3]

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

Function Name: **pmel_t_CO2**

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

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

Input Values

T - Temperature t in °C

Result

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

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

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

Results for wrong input values

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

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

References: [2]

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

Function Name: **psub_t_CO2**

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

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

Input Values

T - Temperature t in °C

Result

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

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

Temperature range: from t_{min} to t_t

Results for wrong input values

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

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

References: [2]

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

Function Name: **Pr_ptx_CO2**

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

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

Input Values

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

Result

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

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

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

Details on the phase fraction x

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2], [3]

Vapor Pressure $p_s = f(t)$

Function Name: **ps_t_CO2**

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

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

Input Values

T - Temperature t in °C

Result

PSTCO2, PS or ps_t_CO2 – Vapor pressure p_s in bar

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

Temperature range: from t_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_t to t_c

Pressure range from p_t to p_c

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

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

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

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

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

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

Pressure range from p_t to p_{\max_Ice}

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

Pressure range from p_t to p_{\max}

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

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

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

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

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

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

Sublimation and

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

Pressure range from p_{\min} to p_t

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2]

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

Function Name: **s_ptx_CO2**

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

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

Input Values

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

Result

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

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

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

Details on the phase fraction x

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

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

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

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

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

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

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

Boiling and dew curve: Temperature range from t_t to t_c

Pressure range from p_t to p_c

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

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

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

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

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

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

Pressure range from p_t to p_{\max_Ice}

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

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

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

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

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

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

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

Sublimation and

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

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2]

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

Function Name: **t_ph_CO2**

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

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

Input Values

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

Result

TPHCO2, T or t_ph_CO2 – Temperature t in °C

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

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

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

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

Details on calculating the two phase regions

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

Results for wrong input values

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

Single phase region:

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

Two phase regions:

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

Melting region:

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

Sublimation region:

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

References: [2]

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

Function Name: **t_ps_CO2**

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

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

Input Values

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

Result

TPSCO2, T or t_ps_CO2 – Temperature t in °C

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

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

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

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

Details on calculating the two phase regions

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

Results for wrong input values

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

Single phase region:

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

Two phase regions:

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

Melting region:

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

Sublimation region:

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

References: [2]

Saturation Temperature $t_s = f(p)$

Function Name: **ts_p_CO2**

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

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

Input Values

P – Pressure p in bar

Result

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

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

Pressure range: from p_t to p_c

Results for wrong input values

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

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

References: [2]

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

Function Name: **tmel_p_CO2**

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

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

Input Values

P – Pressure p in bar

Result

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

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

Pressure range: from p_t to p_{max}

Results for wrong input values

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

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

References: [2]

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

Function Name: **tsub_p_CO2**

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

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

Input Values

P – Pressure p in bar

Result

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

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

Pressure range: from p_{min} to p_t

Results for wrong input values

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

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

References: [2]

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

Function Name: **v_ptx_CO2**

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

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

Input Values

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

Result

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

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

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

Details on the phase fraction x

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

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

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

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

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

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

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

Boiling and dew curve: Temperature range from t_t to t_c

Pressure range from p_t to p_c

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

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

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

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

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

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

Pressure range from p_t to p_{\max_Ice}

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

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

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

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

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

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

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

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

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

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

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

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

References: [2]

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

Function Name: **w_ptx_CO2**

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

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

Input Values

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

Result

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

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

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

Details on the phase fraction x

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Results for wrong input values

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

Single phase region:

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

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

Two phase regions:

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

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

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

Function Name: **x_ph_CO2**

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

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

Input Values

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

Result

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

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

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

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

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

Details on calculating the two phase regions

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

Results for wrong input values

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

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

Two phase regions:

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

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

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

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

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

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

References: [2]

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

Function Name: **x_ps_CO2**

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

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

Input Values

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

Result

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

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

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

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

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

Details on calculating the two phase regions

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

Results for wrong input values

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

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

Two phase regions:

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

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

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

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

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

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

References: [2]

3.3 Property Functions for Solid Carbon Dioxide (Dry Ice)

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

Function Name: **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 m²/s

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

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

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

Results for wrong input values

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

Input Values

P - Pressure p in bar

T - Temperature t in °C

Result

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

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

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

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

Results for wrong input values

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

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

References: [4]

FUNC_310

\$ cpICE = f(t)

K cpICE = f(t)

+ SUCH:310

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

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

Input Values

P - Pressure p in bar

T - Temperature t in °C

Result

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

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

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

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

Results for wrong input values

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

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

References: [4]

FUNC_320

\$ hICE = $f(t)$

K hICE = $f(t)$

+ SUCH:320

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

Function Name: **lambdalCE_t_CO2**

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

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

Input Values

T - Temperature t in °C

Result

LAMICETCO2, LAM or **lambdalCE_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 **lambdalCE_t_CO2 = -1000** for input values:

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

References: [5]

FUNC_330

\$ lambdalCE = $f(t)$

K lambdalCE = $f(t)$

+ SUCH:330

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

Function Name: **rhoICE_pt_CO2**

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

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

Input Values

P - Pressure p in bar

T - Temperature t in °C

Result

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

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

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

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

Results for wrong input values

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

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

References: [4]

FUNC_340

\$ rhoICE = f(t)

K rhoICE = f(t)

+ SUCH:340

#\$K⁺ Specific Entropy $s = f(p, t)$

Function Name: **sICE_pt_CO2**

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

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

Input Values

P - Pressure p in bar

T - Temperature t in °C

Result

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

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

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

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

Results for wrong input values

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

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

References: [4]

FUNC_350

\$ sICE = $f(t)$

K sICE = $f(t)$

+ SUCH:350

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

Function Name: **vICE_pt_CO2**

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

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

Input Values

P - Pressure p in bar

T - Temperature t in °C

Result

VICEPTCO2, V or **vICE_pt_CO2** – specific volume v in m³/kg

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

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

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

Results for wrong input values

Result **VICEPTCO2 = -1000, V = -1000** or **vICE_pt_CO2 = -1000** for input values:

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

References: [4]

FUNC_360

\$ vICE = $f(t)$

K vICE = $f(t)$

+ SUCH:360

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

Function Name: **tICE_ph_CO2**

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

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

Input Values

P - Pressure p in bar

H – Specific enthalpy h in kJ/kg

Result

TICEPHCO2, T or tICE_ph_CO2 - Temperature in °C

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

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

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

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

Results for wrong input values

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

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

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

References: [4]

FUNC_370

\$ tICE = f(h)

K tICE = f(h)

+ SUCH:370

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

Function Name: **tICE_ps_CO2**

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

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

Input Value

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

Result

TICEPSCO2, T or tICE_ps_CO2 - Temperature in °C

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

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

Results for wrong input values

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

References: [4]

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

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

Water and Steam

Library LibIF97

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

Library LibIF97_META

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

Humid Combustion Gas Mixtures

Library LibHuGas

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

Humid Air

Library LibHuAir

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

Extremely Fast Property Calculations

- Spline-Based Table
 Look-up Method (SBTL)

Library LibSBTL_IF97 Library LibSBTL_95 Library LibSBTL_HuAir

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

Carbon Dioxide Including Dry Ice

Library LibCO2

- Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

- IAPWS Industrial Formulation 2013

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

- Model: Ideal mixture of the ideal gases:
- | | | | |
|---------------|----------------------|---------------|------------|
| Ar | NO | He | Propylene |
| Ne | H_2O | F_2 | Propane |
| N_2 | SO_2 | NH_3 | Iso-Butane |
| O_2 | H_2 | Methane | n-Butane |
| CO | H_2S | Ethane | Benzene |
| CO_2 | OH | Ethylene | Methanol |
| Air | | | |

- Consideration of:
 • Dissociation from the VDI Guideline 4670

Library LibIDGAS

- Model: Ideal gas mixture from VDI Guideline 4670
 Consideration of:
 • Dissociation from the VDI Guideline 4670

Humid Air

Library ASHRAE LibHuAirProp

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

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

Dry Air Including Liquid Air

Library LibRealAir

- Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

- Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

- Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

- Formulation of Bücker and Wagner (2006)

n-Butane

Library LibButane_n

- Formulation of Bücker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

Water/Lithium Bromide Mixtures

Library LibWaLi

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

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

- Liquid solutions of water with
- | | |
|-----------------------------------|---------------------|
| $\text{C}_2\text{H}_6\text{O}_2$ | 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 et al. (2014)

Methanol

Library LibCH3OH

Formulation of
de Reuck and Craven (1993)

Propane

Library LibPropane

Formulation of
Lemmon et al. (2009)

Siloxanes as ORC Working Fluids

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

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Nitrogen and Oxygen

Libraries LibN2 and LibO2

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

Hydrogen

Library LibH2

Formulation of
Leachman et al. (2009)

Helium

Library LibHe

Formulation of
Arp et al. (1998)

Hydrocarbons

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

Isopentane C_5H_{12} **Library LibC5H12_Iso**

Neopentane C_5H_{12} **Library LibC5H12_Neo**

Isohexane C_6H_{14} **Library LibC6H14**

Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

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

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

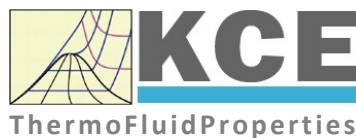
Hydrogen sulfide **H₂S** **Library LibH2S**

Nitrous oxide **N₂O** **Library LibN2O**

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

Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)



For more information please contact:

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

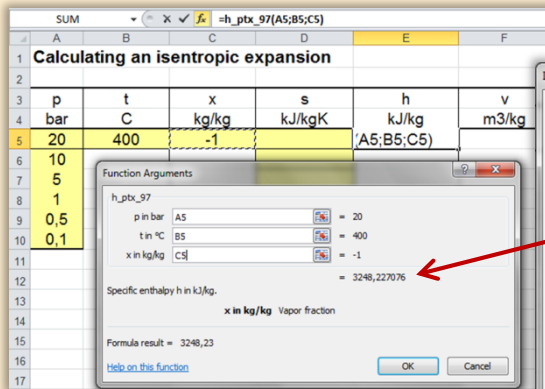
Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

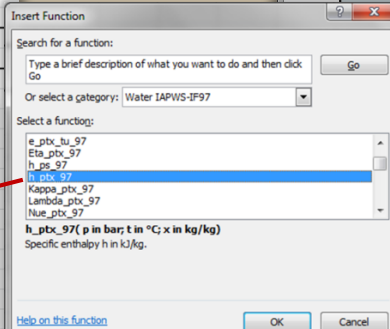
^a Not all of these property functions are available in all property libraries.

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

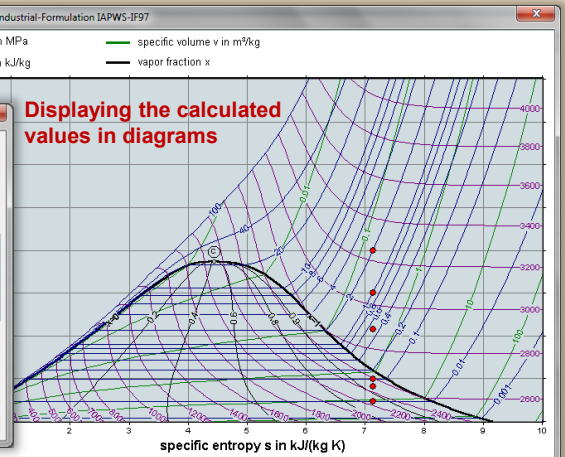
Add-In **FluidEXL** Graphics for Excel®



Choosing a property library and a function



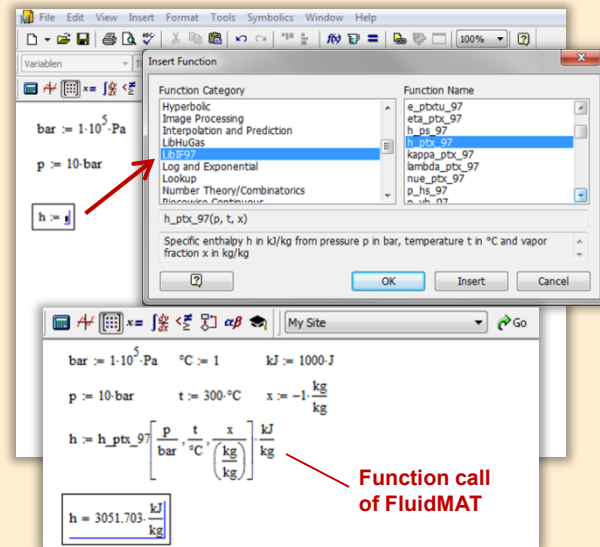
Displaying the calculated values in diagrams



Menu for the input of given property values

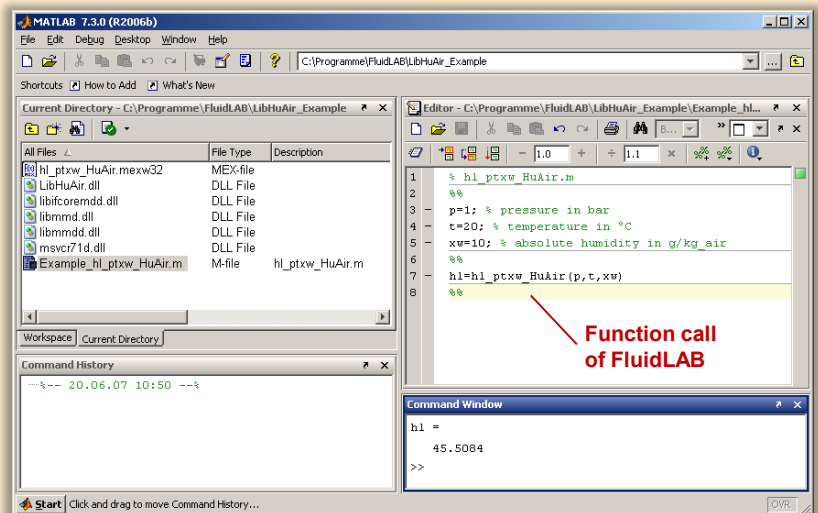
Add-On **FluidMAT** for Mathcad®
 Add-On **FluidPRIME** for Mathcad Prime®

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



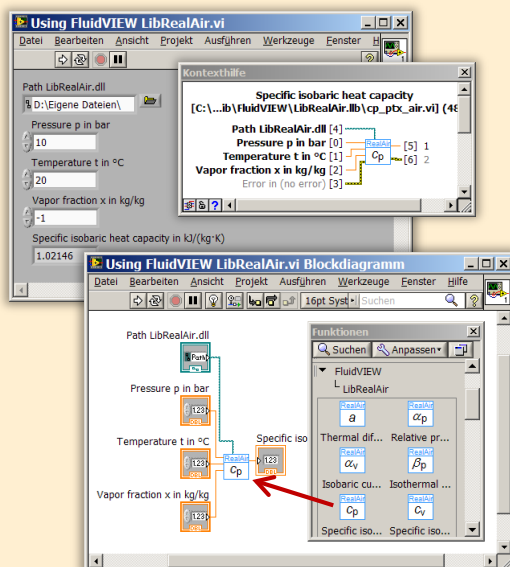
Add-On **FluidLAB** for MATLAB® and SIMULINK®

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



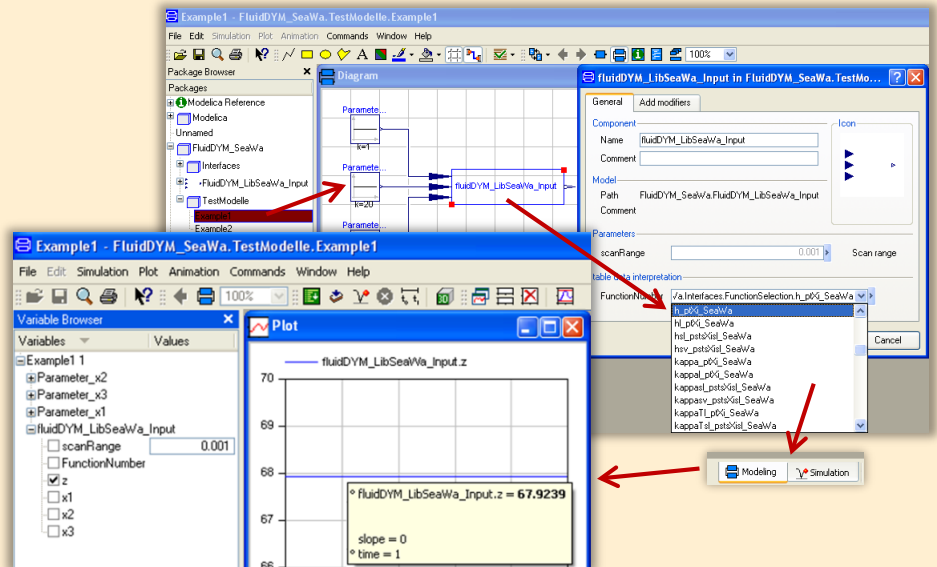
Add-On **FluidVIEW** for LabVIEW™

The property functions can be calculated in LabVIEW™.

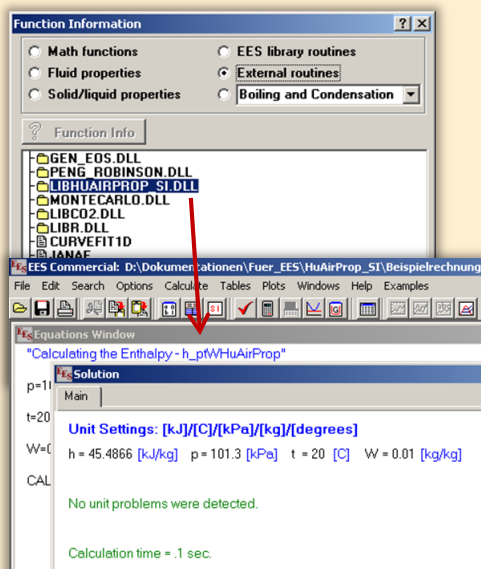


Add-On **FluidDYM** for DYMOLA® (Modelica) and SimulationX®

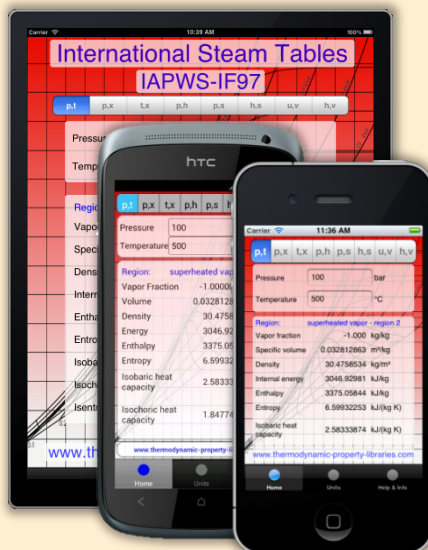
The property functions can be called in DYMOLA® and SimulationX®.



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



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



Online Property Calculator at www.thermofluidprop.com

Zittau's Fluid Property Calculator

Fluid:

Function:

Unit System:

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

Pressure p: bar

Temperature t: °C

Vapor fraction x: kg/kg

Calculate / Recalculate

Result:

Specific enthalpy h = 3097.38 kJ/kg

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

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

PDF with the description

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Fax: +49-3583-61-1946
E-mail: info@thermofluidprop.com
www.thermofluidprop.com
www.thermofluidprop.com
www.thermofluidprop.com
www.thermofluidprop.com

Property Software for Pocket Calculators

FluidCasio



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

FluidHP



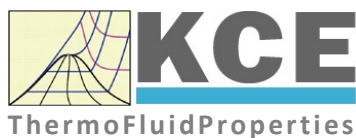
HP 48 HP 49

FluidTI



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

For more information please contact:



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

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

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

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

5. References

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

6. Satisfied Customers

Date: 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
Pöyry, 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, Sønderborg, 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, Härklingen, Schweiz	02/2018
Ingenieurbüro Leipert, Riegelsberg	02/2018
AIXPROCESS, Aachen	02/2018
KRONES, Neutraubling	02/2018
Doosan Lentjes, Ratingen	01/2018

2017

Compact Kältetechnik, Dresden	12/2017
Endress + Hauser Messtechnik GmbH +Co. KG, Hannover	12/2017
TH Mittelhessen, Gießen	11/2017
Haarslev Industries, Sønderød, 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
Pöyry Deutschland GmbH, Dresden	09/2016
Siemens AG, Erlangen	09/2016
BASF über Fichtner IT Consulting AG	09/2016
B+B Engineering GmbH, Magdeburg	09/2016
Wilhelm Büchner Hochschule, Pfungstadt	08/2016

Webasto Thermo & Comfort SE, Gliching	08/2016
TU Dresden, Dresden	08/2016
Endress+Hauser Messtechnik GmbH+Co. KG, Hannover	08/2016
D + B Kältetechnik, Althausen	07/2016
Fichtner IT Consulting AG, Stuttgart	07/2016
AB Electrolux, Krakow, Poland	07/2016
ENEXIO Germany GmbH, Herne	07/2016
VPC GmbH, Vetschau/Spreewald	07/2016
INWAT, Lodz, Poland	07/2016
E.ON SE, Düsseldorf	07/2016
Planungsbüro Waidhas GmbH, Chemnitz	07/2016
EEB Enerko, Aldershoven	07/2016
IHEBA Naturenergie GmbH & Co. KG, Pfaffenhofen	07/2016
SSP Kälteplaner AG, Wolfertschwenden	07/2016
EEB ENERKO Energiewirtschaftliche Beratung GmbH, Berlin	07/2016
BOGE Kompressoren Otto BOGE GmbH & Co KG, Bielefeld	06/2016
Universidad Carlos III de Madrid, Madrid, Spain	04/2016
INWAT, Lodzi, Poland	04/2016
Planungsbüro Waidhas GmbH, Chemnitz	04/2016
STEAG Energy Services GmbH, Laszlo Küppers, Zwingenberg	03/2016
WULFF & UMAG Energy Solutions GmbH, Husum	03/2016
FH Bielefeld, Bielefeld	03/2016
EWT Eckert Wassertechnik GmbH, Celle	03/2016
ILK Institut für Luft- und Kältetechnik GmbH, Dresden	02/2016, 06/2016
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
Rudolf 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
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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
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Schniewindt GmbH & Co. KG, Neuenwalde	08/2015

2014

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GKS, Schweinfurt	03/2014
Technical University of Nuremberg	03/2014
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2013

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	11/2013
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Brunner Energieberatung, Zurich, Switzerland	07/2013
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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
Fichtner IT, Stuttgart	10/2012, 11/2012
Helbling Technik AG, Zurich, Switzerland	10/2012
University of Duisburg	10/2012

Rerum Cognitio Forschungszentrum, Frankfurt	09/2012
Pöyry Deutschland GmbH, Dresden	08/2012
Extracciones, Guatemala	08/2012
RWE, Essen	08/2012
Weghaus Consulting Engineers, Wuerzburg	08/2012
GKS, Schweinfurt	07/2012
COMPAREX, Leipzig for RWE Essen	07/2012
GEA, Nobitz	07/2012
Meyer Werft, Papenburg	07/2012
STEAG, Herne	07/2012
GRS, Cologne	06/2012
Fichtner IT Consult, Chennai, India	06/2012
Siemens, Freiburg	06/2012
Nikon Research of America, Belmont, USA	06/2012
Niederrhein University of Applied Sciences, Krefeld	06/2012
STEAG, Zwingenberg	06/2012
Mainova, Frankfurt on Main via Fichtner IT Consult	05/2012
Endress & Hauser	05/2012
PEU, Espenheim	05/2012
Luzern University of Applied Sciences, Switzerland	05/2012
BASF, Ludwigshafen (general license) via Fichtner IT Consult	05/2012
SPX Balcke-Dürr, Ratingen	05/2012, 07/2012
Gruber-Schmidt, Wien, Austria	04/2012
Vattenfall, Berlin	04/2012
ALSTOM, Baden	04/2012
SKW, Piesteritz	04/2012
TERA Ingegneria, Trento, Italy	04/2012
Siemens, Erlangen	04/2012, 05/2012
LAWI Power, Dresden	04/2012
Stadtwerke Leipzig	04/2012
SEITZ, Wetzikon, Switzerland	03/2012, 07/2012
M & M, Bielefeld	03/2012
Sennheiser, Wedemark	03/2012
SPG, Montreuil Cedex, France	02/2012
German Destillation, Sprendlingen	02/2012
Lopez, Munguia, Spain	02/2012
Endress & Hauser, Hannover	02/2012
Palo Alto Research Center, USA	02/2012
WIPAK, Walsrode	02/2012
Freudenberg, Weinheim	01/2012
Fichtner, Stuttgart	01/2012
airinotec, Bayreuth	01/2012, 07/2012
University Auckland, New Zealand	01/2012
VPC, Vetschau	01/2012
Franken Guss, Kitzingen	01/2012

2011

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

ILK Dresden
 Technical University of Dresden

01/2011
 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
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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

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

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

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STORA ENSO Sachsen, Eilenburg	01/2006
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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	
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Chair in Apparatus and Plant Engineering	
Energietechnik Leipzig (company license),	02/2006
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RWE Power, Essen	03/2006
WAETAS, Pobershau	04/2006
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Department of Thermodynamics	
EnviCon & Plant Engineering, Nuremberg	04/2006
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University of Halle-Merseburg,	05/2006
Department of USET Merseburg incorporated society	
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Department of Mechanical Engineering	
Siemens Power Generation, Berlin	11/2006
Zikesch Armaturentechnik, Essen	11/2006
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BASF, Schwarzheide	12/2006
Enertech Energie und Technik, Radebeul	12/2006

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

Technical University of Dresden, Waste Management	05/2005
Siemens Power Generation, Goerlitz	05/2005
Duesseldorf University of Applied Sciences, Department of Mechanical Engineering and Process Engineering	05/2005
Redacom, Nidau, Switzerland	06/2005
Dumas Verfahrenstechnik, Hofheim	06/2005
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Stadtwerke Leipzig	07/2005
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Basel University of Applied Sciences, Department of Mechanical Engineering, Switzerland	10/2005
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h s energieanlagen, Freising	07/2004
FCIT, Stuttgart	08/2004
Physikalisch Technische Bundesanstalt (PTB), Braunschweig	08/2004
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Rietschle Energieplaner, Winterthur, Switzerland	08/2004
MAN Turbo Machines, Oberhausen	09/2004
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energeticals (e-concept), Munich	11/2004
SorTech, Halle	11/2004

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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
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Rietschle Energieplaner, Winterthur, Switzerland	02/2003
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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
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Erfurt University of Applied Sciences, Department of Supply Engineering	12/2003
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MVV Energie, Mannheim	02/2001
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DVO Data Processing Service, Oberhausen	05/2000
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Technical University of Graz, Department of Thermal Engineering, Austria	11/1999
Ostendorf Engineering, Gummersbach	12/1999

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SCA Hygiene Products, Munich	10/1998
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