Property Library for
Ice
Water
and Steam

FluidEXL *Graphics*
with LibIce
for Excel®

Prof. Dr. Hans-Joachim Kretzschmar
Prof. Dr. Matthias Kunick
Dr. Sebastian Herrmann
M.Eng Martin Suender
Tobias Göpfert

Software for the Calculation of the Properties

of Ice, Water and Steam

Including DLL and Add-In for Excel®

FluidEXL *Graphics*
LibIce

Contents

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0 Package Contents

0.1   Zip files for 64-bit Office®

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

   CD_FluidEXL_Graphics_Eng_LibIce_x64.zip

including the following folders an files:

   \FLUFT\

   \Formulation97\

   FluidEXL_Graphics_LibIce_Docu_Eng.pdf

   FluidEXL_Graphics_Eng.xla

   LC.dll

   LibIce.dll

   LibIce.chm.

0.2   Zip files for 32-bit Office®

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

   CD_FluidEXL_Graphics_Eng_LibIce.zip

including the following folders and files:

   \FLUFT\

   \Formulation97\

   FluidEXL_Graphics_LibIce_Docu_Eng.pdf

   FluidEXL_Graphics_Eng.xla

   LC.dll

   LibIce.dll

   LibIce.chm.

1. Property Functions

1.1 Property Functions of LibICE

Functional Dependence	Function Name	Fortran Program	Property or Function	Unit of the Result
$a = f(p,t,x)$	a_ptx_ICE	APTXICE(P,T,X)	Thermal diffusivity	m^2/s
$\alpha_v = f(p,t,x)$	alphav_ptx_ICE	ALPHAVPTXICE(P,T,X)	Isobaric cubic expansion coefficient	1/K
$c_p = f(p,t,x)$	cp_ptx_ICE	CPPTXICE(P,T,X)	Specific isobaric heat capacity	kJ/(kg K)
$c_v = f(p,t,x)$	cv_ptx_ICE	CVPTXICE(P,T,X)	Specific isochoric heat capacity	kJ/(kg K)
$\eta = f(p,t,x)$	eta_ptx_ICE	ETAPTXICE(P,T,X)	Dynamic viscosity (only for liquid and steam)	Pa s
$h = f(p,t,x)$	h_ptx_ICE	HPTXICE(P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p,t,x)$	kappa_ptx_ICE	KAPPAPTXICE(P,T,X)	Isentropic exponent	-
$\kappa_T = f(p,t,x)$	kappaT_ptx_ICE	KAPPATPTXICE(P,T,X)	Isothermal compressibility	1/kPa
$\lambda = f(p,t,x)$	lambda_ptx_ICE	LAMBDAPTXICE(P,T,X)	Thermal conductivity	W/(m K)
$p_{mel} = f(t)$	pmel_t_08_ICE	PMEL_T_08_ICE(T)	Melting pressure	bar
$p_s = f(t)$	ps_t_97_ICE	PS_T_97_ICE(T)	Vapor pressure	bar
$p_{sub} = f(t)$	psub_t_08_ICE	PSUB_T_08_ICE(T)	Sublimation pressure	bar
$\rho = f(p,t,x)$	rho_ptx_ICE	RHOPTXICE(P,T,X)	Density	kg/m³

Functional Dependence	Function Name	Fortran Program	Property or Function	Unit of the Result
$s = f(p,t,x)$	s_ptx_ICE	SPTXICE(P,T,X)	Specific entropy	kJ/(kg K)
$t = f(p,h)$	t_ph_ICE	TPHICE(P,H)	Backward function: Temperature from pressure and specific enthalpy	°C
$t = f(p,s)$	t_ps_ICE	TPSICE(P,S)	Backward function: Temperature from pressure and specific entropy	°C
$t_{mel} = f(p)$	tmel_p_08_ICE	TMEL_P_08_ICE(P)	Melting temperature	°C
$t_s = f(p)$	ts_p_97_ICE	TS_P_97_ICE(P)	Saturation temperature	°C
$t_{sub} = f(p)$	tsub_p_08_ICE	TSUB_P_08_ICE(P)	Sublimation temperature	°C
$u = f(p,t,x)$	u_ptx_ICE	UPTXICE(P,T,X)	Specific internal energy	kJ/kg
$v = f(p,t,x)$	v_ptx_ICE	VPTXICE(P,T,X)	Specific volume	m³/kg
$w = f(p,t,x)$	w_ptx_ICE	WPTXICE(P,T,X)	Isentropic speed of sound	m/s
$x = f(p,h)$	x_ph_ICE	XPHICE(P,H)	Backward function: Phase fraction from pressure and specific enthalpy	kg/kg
$x = f(p,s)$	x_ps_ICE	XPSICE(P,S)	Backward function: Phase fraction from pressure and specific entropy	kg/kg

Units: p in bar

t in °C

x in kg/kg (Phase fraction; see description in the following)

Reference State:

$h = 0.0006118$ kJ/kg and $s = 0$ kJ/(kg K)

at $p_t = 6.11657 \cdot 10^{-3}$ bar and $t_t = 0.01$ °C (273.16 K)

Details on the Phase Fraction *x*

If the state point to be calculated is located in one of the single phase regions ice, liquid, superheated steam or gas, $x = -1$ must be entered as a pro-forma value. Here the backward functions will result in $x = -1$.

The two phase regions wet stem region, melting region and sublimation region (see log *p-h* diagram in Chapter 1.2) are divided automatically by the subprograms. Please consider the following facts:

1. Wet Stem Region (0 ≤ *x* ≤ 1):

The phase fraction *x* equates to the vapor fraction *x* in the wet steam region $x = \dfrac{m''}{(m' + m'')}$. Its unit is (kg saturated steam)/(kg wet steam).

When calculating properties of wet steam, a value between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) has to be entered for *x*. In this case, the backward functions result in the appropriate value between 0 and 1 for *x*.

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 steam, the program will consider *p* and *t* to be appropriate to represent the vapor pressure curve. If it is not the case the calculation for the quantity of the chosen function results in -1000.

Wet steam region: Temperature ranges from $t_t = 0.01$ °C (273.16 K) to $t_{max} = 350$ °C (623.15 K)

Pressure ranges from $p_t = 6.11657 \cdot 10^{-3}$ bar to $p_s (t_{max}) = 165.291643$ bar

2. Melting Region (10 ≤ *x* ≤ 11):

The phase fraction *x* equates to the liquid fraction x in the melting region $x = 10 + \dfrac{m_{liq}}{(m_{ice} + m_{liq})}$. Its unit is (kg solidified liquid)/(kg melt), whereas melt is a mixture of melting ice and solidified liquid.

When calculating properties of the melting region, a value between 10 and 11 ($x = 10$ for saturated solid, $x = 11$ for saturated liquid) has to be entered for *x*. In this case, the backward functions result in the appropriate value between 10 and 11 for *x*.

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 results in -1000.

Melting region: Temperature ranges from $t_{mel}(p_{max}) = -8.9412$ °C (264.2088 K) to $t_t = 0.01$ °C (273.16 K)

Pressure ranges from $p_t = 6.11657 \cdot 10^{-3}$ bar to $p_{max} = 1000$ bar

3. Sublimation Region (100 ≤ x ≤ 101):

The phase fraction x equates to the gas fraction x in the sublimation region $x = 100 + \dfrac{m_{\text{gas}}}{\left(m_{\text{ice}} + m_{\text{gas}}\right)}$. Its unit is (kg desublimated gas)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimated ice and desublimated gas.

When calculating properties of sublimation region, a value between 100 and 101 (x = 100 for saturated ice, x = 101 for saturated gas) has to be entererd for x. In this case, the backward functions result in the appropriate value between 100 and 101 for x.

In this case it is adequate to enter either the given value for t <u>and</u> p = −1000, or the given value for p <u>and</u> t = −1000, plus the value for x between 100 and 101. If values for both p <u>and</u> t are entered, the program will consider p <u>and</u> 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 results in −1000.

Sublimation region: Temperature ranges from t_{min} = −223.15 °C (50 K) to t_{t} = 0.01 °C (273.16 K)

Pressure ranges from $p_{\text{min}} = p_{\text{sub}}(t_{\text{min}})$ = 1.9349584868·10^{-45} bar to p_{t} = 6.11657·10^{-3} 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 program documentation in Chapter 3. The same information may also be accessed via the online help pages.

1.2   Range of Validity of LibICE

The LibICE property library calculates the thermodynamic and transport properties of ice lh, water and steam. As shown in the following p-T and log p-h diagrams, different formulations are used to describe the entire Range of validity of LibICE.

The thermodynamic properties of ice lh are calculated by the IAPWS Formulation 2006 [5]. This region is marked with green color in the following log p-T diagram. This region ranges from minimum pressure to maximum pressure and from minimum temperature to the melting temperature for pressures $p \geq p_t$ and to the sublimation temperature for pressures $p < p_t$. The melting and sublimation pressures are calculated from the IAPWS 2008 Formulation [6].

The liquid-water region ranges from triple point pressure to maximum pressure and from melting temperature to saturation temperature for $p \leq p_s(T_{max})$ and the maximum temperature for $p > p_s(T_{max})$. In this region, the fundamental equation of IAPWS-IF97 Region 1 [1,2] is used. This region is marked with blue color in the following p-T diagram.

The vapor region covers the range from minimum pressure to saturation pressure and from triple point temperature to the maximum temperature for pressures $p < p_t$ and from saturation temperature to maximum temperature for pressures $p \geq p_t$. The thermodynamic properties are calculated by the fundamental equation of IAPWS-IF97 Region 2 [1,2]. This region is marked with light red color in the following p-T diagram.

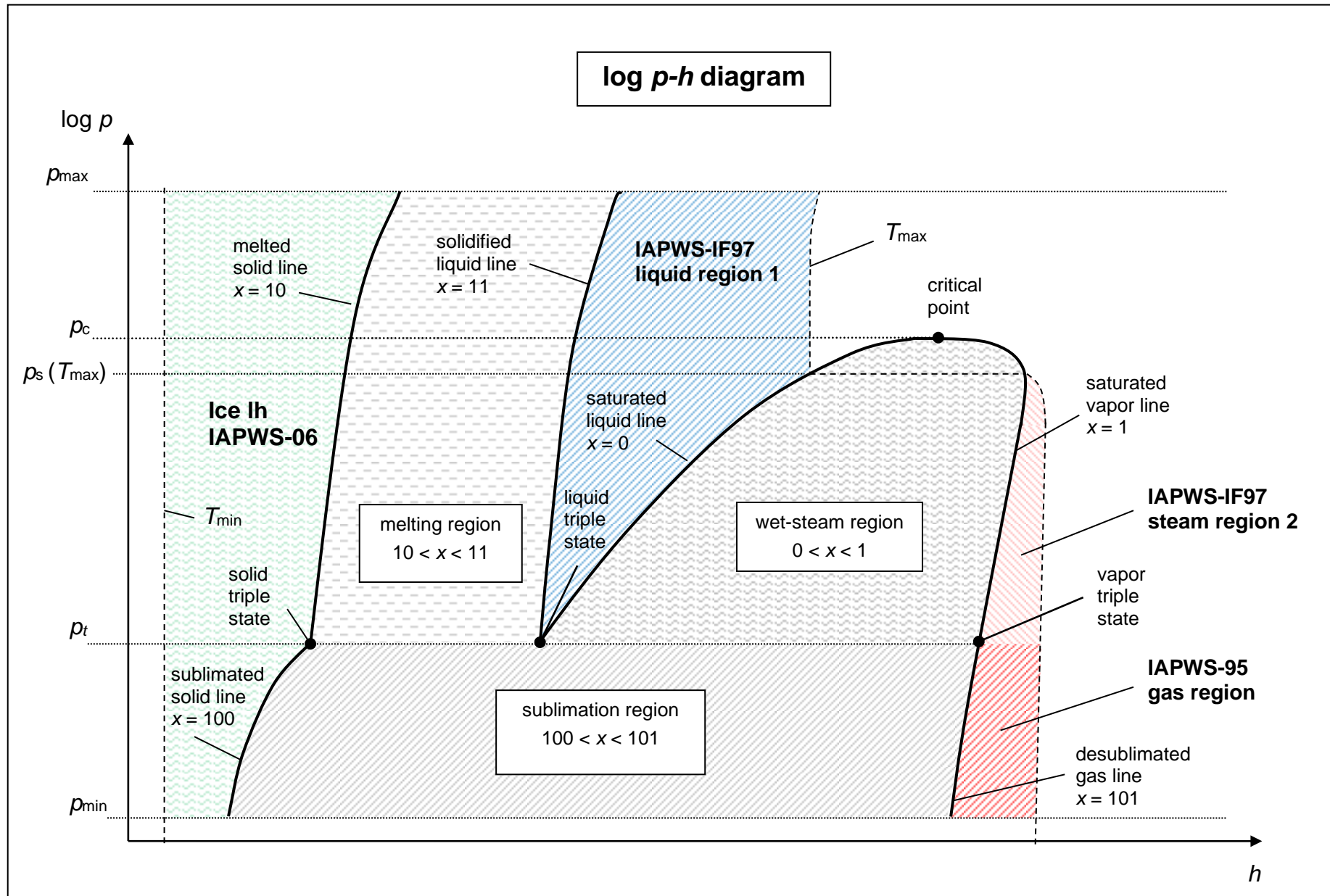The red region in the p-T diagram is covered by the Scientific Formulation IAPWS-95 [5]. This region covers the range from minimum pressure to the sublimation pressure and from sublimation temperature to the triple point temperature.

For given property values, the region is chosen automatically by the subprograms. The two-phase regions wet steam region, melting region and sublimation region are also chosen automatically.

p-T diagram
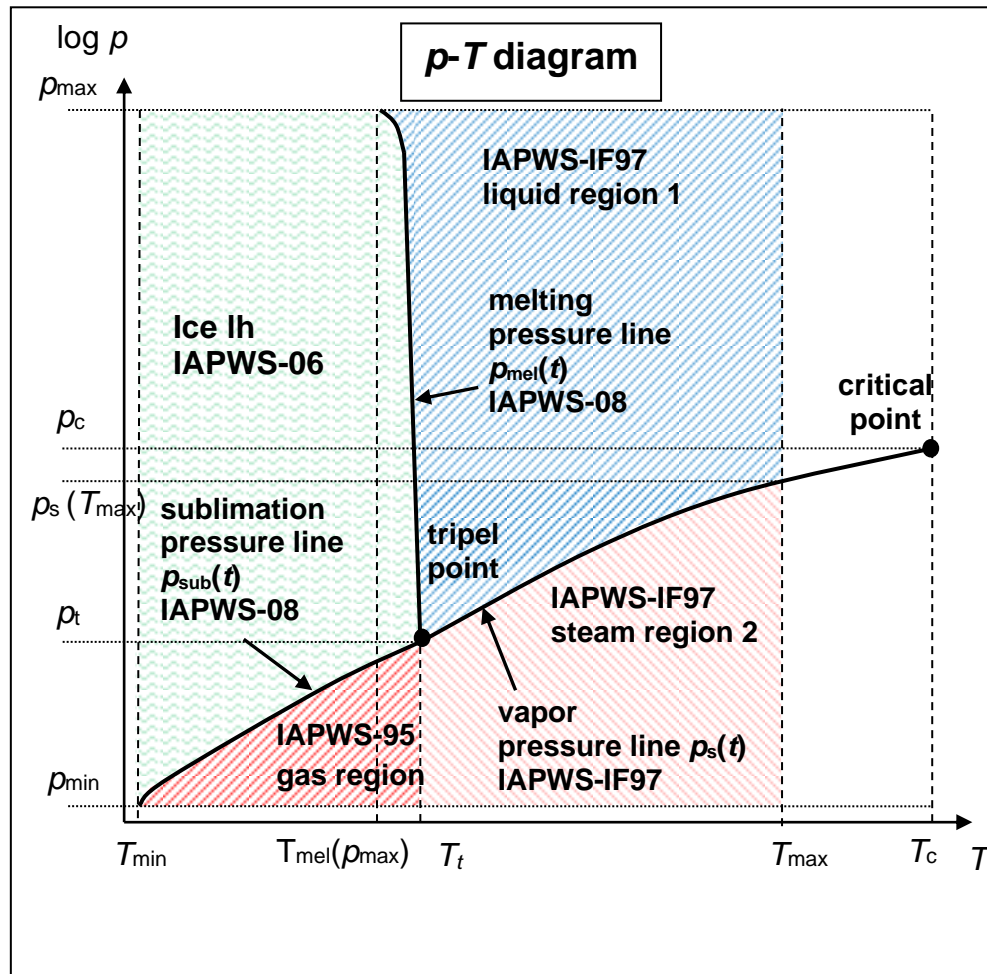
Values at Important State Points

Property	Variable	Value and Unit
Minimum temperature	T_{min}	50 K (– 223.15 °C)
Maximum temperature	T_{max}	623.15 K (350 °C)
Triple temperature	T_t	273.16 K (0.01 °C)
Temperature at the critical point	T_c	647.096 K (373.946 °C)
Melting temperature at maximum pressure	$T_{mel}(p_{max})$	264.2088 K (–8.9412 °C)
Minimum pressure	$p_{min}=p_{sub}(T_{min})$	$1.9349584868 \cdot 10^{-46}$ MPa
Maximum pressure	p_{max}	100 MPa
Triple pressure	p_t	$6.11657 \cdot 10^{-4}$ MPa
Pressure at the critical point	p_c	22.064 MPa
Vapor pressure at maximum temperature	$p_s(T_{max})$	16.5291643 MPa

KCE-ThermoFluidProperties, Prof. Dr. Hans-Joachim Kretzschmar

log *p-h* diagram

2. Application of FluidEXL *Graphics* in Excel®

The FluidEXL *Graphics* Add-In has been developed to calculate thermodynamic properties in Excel® more conveniently. Within Excel®, it enables the direct call of functions relating to Water and Steam from the LibIce property program library.

2.1 Installing FluidEXL *Graphics*

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

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

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

After you have downloaded and extracted the zip-file:

    CD_FluidEXL_Graphics_LibIce_x64_Eng.zip   (for 64 bit version)

or

    CD_FluidEXL_Graphics_LibIce_Eng.zip"   (for 32 bit version).

you will see the folder

    \CD_FluidEXL_Graphics_LibIce_x64_Eng\   (for 64 bit version)

or

    \CD_FluidEXL_Graphics_LibIce_Eng\   (for 32 bit version)

in your Windows Explorer, Total Commander etc.

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

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

    \FLUFT\
    \Formulation97\
    FluidEXL_Graphics_Eng.xla
    FluidEXL_Graphics_LibIce_Docu_Eng
    LC.dll
    LibIce.dll
    LibIce.chm
    Reg_.reg

Now, please copy the following folders and files

    \FLUFT\
    \Formulation97\
    FluidEXL_Graphics_Eng.xla
    LibIce.dll
    LibIce.chm
    LC.dll

into the folder

    C:\Users\[your name]\AppData\Roaming\Microsoft\AddIns\,

where [your name] is your name in the Windows system.

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

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

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

- Click the "File" button in the upper left hand corner of Excel® (see Fig. 2.1)
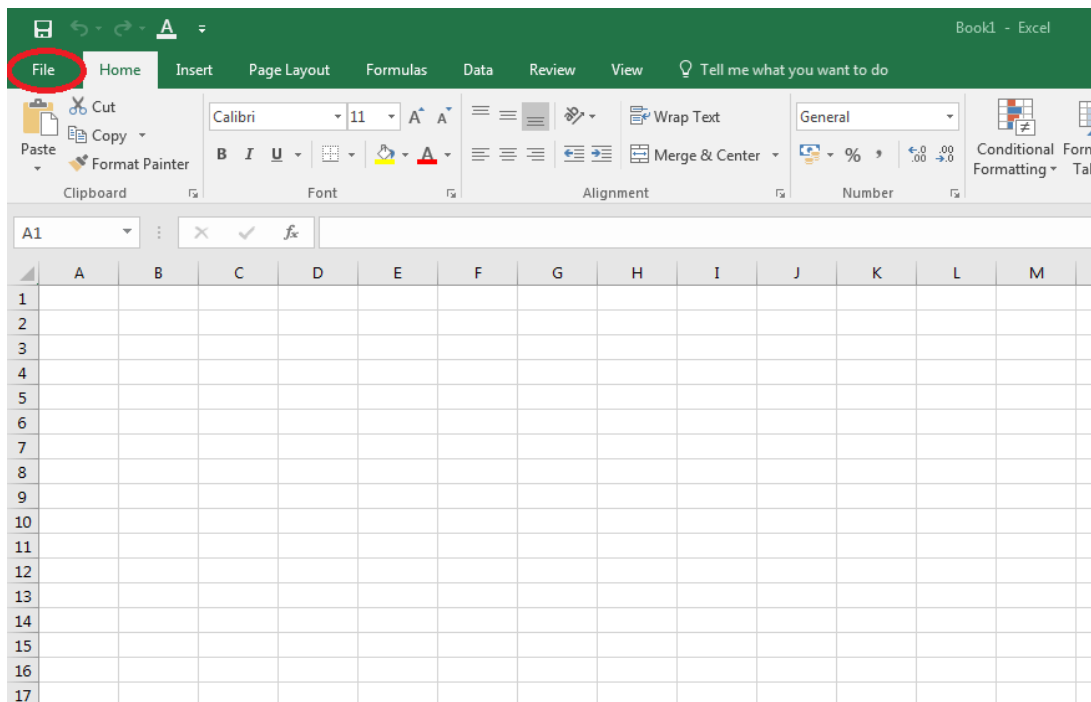
Figure 2.1: Registering FluidEXL*Graphics* as Add-In in Excel® 2016

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

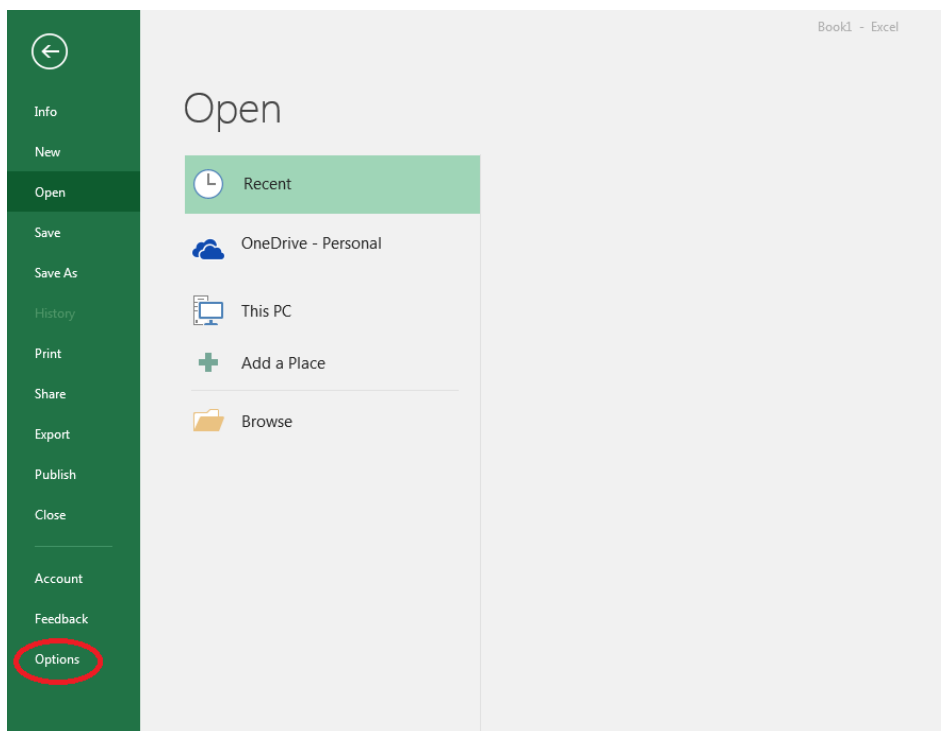**Figure 2.2:** Registering FluidEXL*Graphics* as Add-In in Excel® 2016

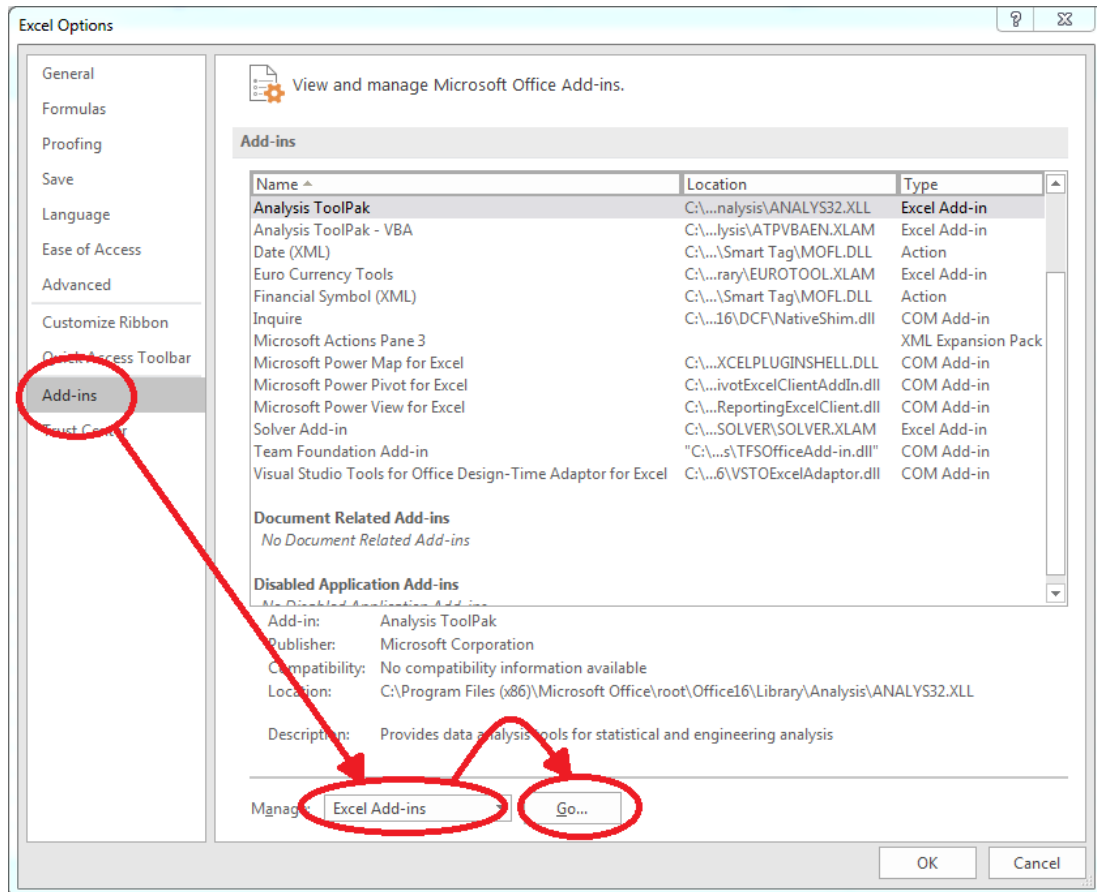- Click on "Add-Ins" in the next menu (Fig. 2.3)

Figure 2.3: Dialog window "Excel Options"

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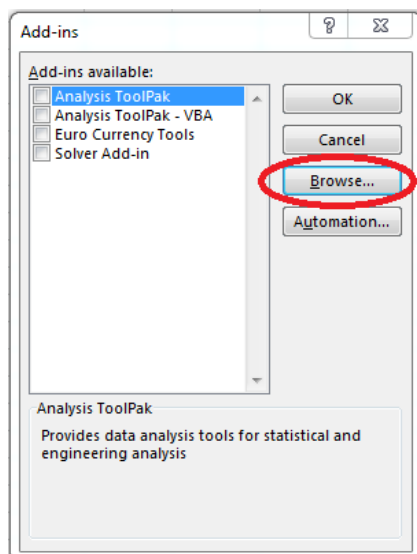

Figure 2.4: Dialog window "Add-ins"

- Excel opens the AddIns folder. This is usually

  C:\Users\[your name]\AppData\Roaming\Microsoft\AddIns\.

- If the FluidEXL files have already been copied to this directory in section 2.1, please skip the following indented section. If not, follow the indented instructions to successful paste the needed files for the FluidEXL Add-In:

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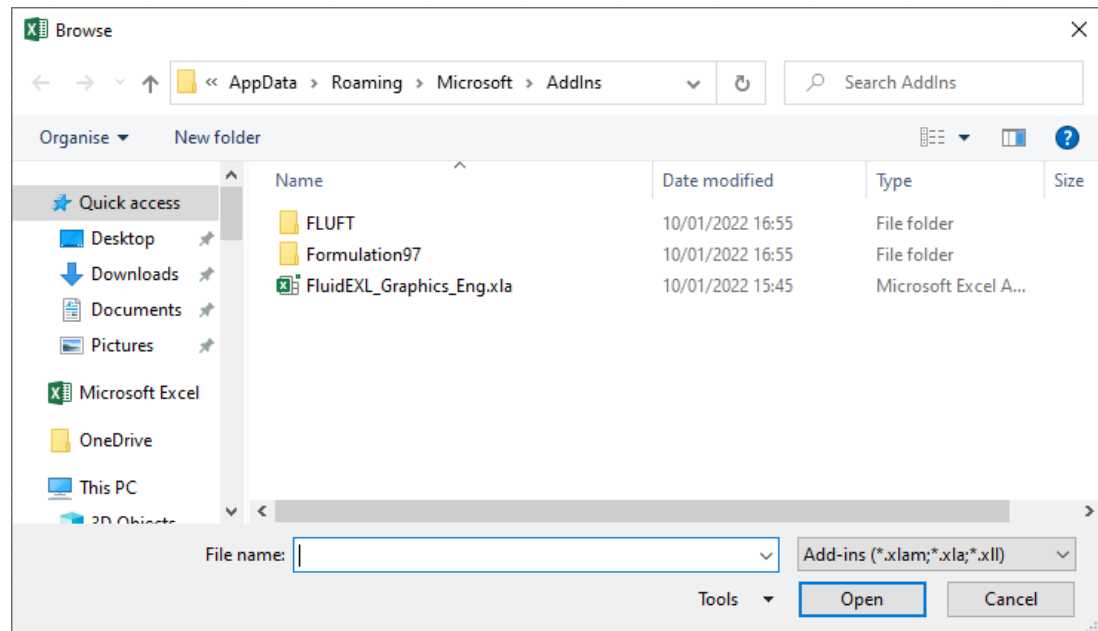
Figure 2.5: "Browse"-Window

  > Please copy this path and paste it into your file manager.
  > Now, please copy the following directories and files:
  >
  > > \FLUFT\
  > > \Formulation97\
  > > LC.dll
  > > FluidEXL_Graphics_Eng.xla
  > > LibIce.dll
  > > LibIce.chm
  >
  > from the delivered CD-folder into this folder.

- Click "FluidEXL_Graphics_Eng.xla" in this folder (see Fig. 2.5) and click "OK."

- Now, "FluidEXL Graphics Eng" will be shown in the list of Add-ins (see Fig. 2.6).

  (If a checkmark is in the box next to the name "FluidEXL Graphics Eng", this Add-In will automatically be loaded whenever Excel starts. This will continue to occur unless the checkmark is removed from the box by clicking on it.)

- In order to register the Add-In click the "OK" button in the "Add-ins" window (see Fig. 2.6).
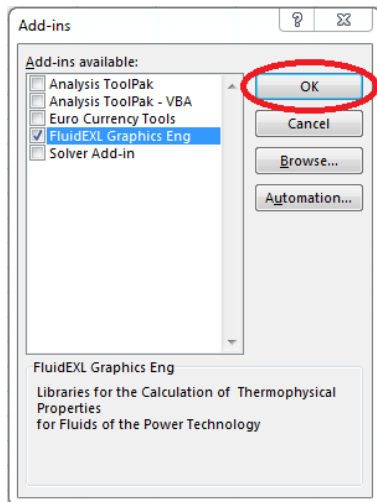
Figure 2.6: Dialog window "Add-Ins"

In order to use FluidEXL^{Graphics} in the following example, click on the menu item "Add-Ins" shown in Fig. 2.7.
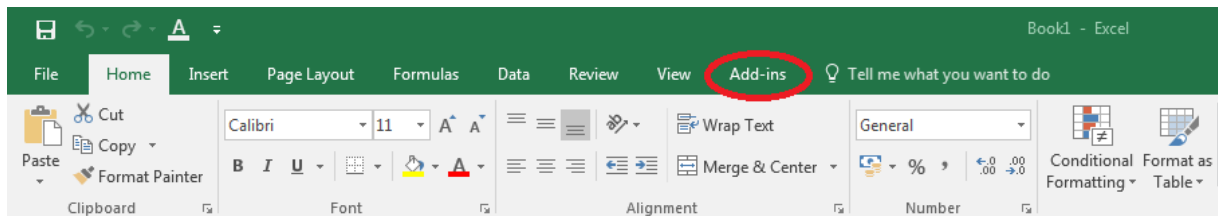
Figure 2.7: Menu item "Add-Ins"

In the upper menu region of Excel$^®$, the FluidEXL^{Graphics} menu bar will appear as marked with the red circle in Fig. 2.8.
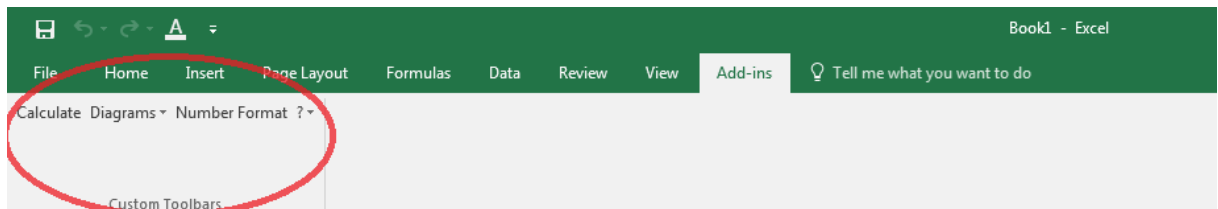
Figure 2.8: FluidEXL^{Graphics} menu bar

The Installation of FluidEXL^{Graphics} in Excel$^®$ is now complete.

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

2.3   Licensing the LibIce Property LibIcerary

The licensing procedure has to be carried out when Excel$^®$ starts up and a FluidEXL^{Graphics} prompt message appears. In this case, you will see the "License Information" window (see figure below).
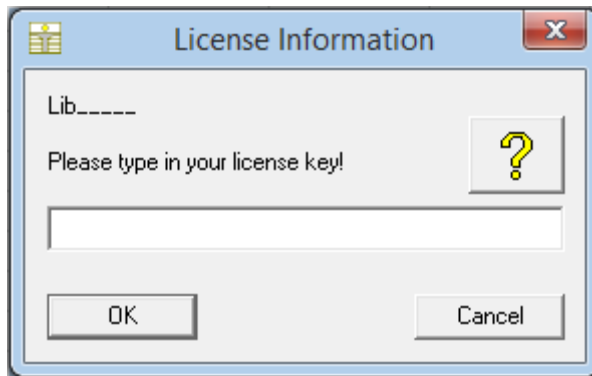
Figure 2.12: "License Information" window

Here you will have to type in the license key. You can find contact information on the "Content" page of this User's Guide or by clicking the yellow question mark in the "License Information" window. Then the following window will appear:
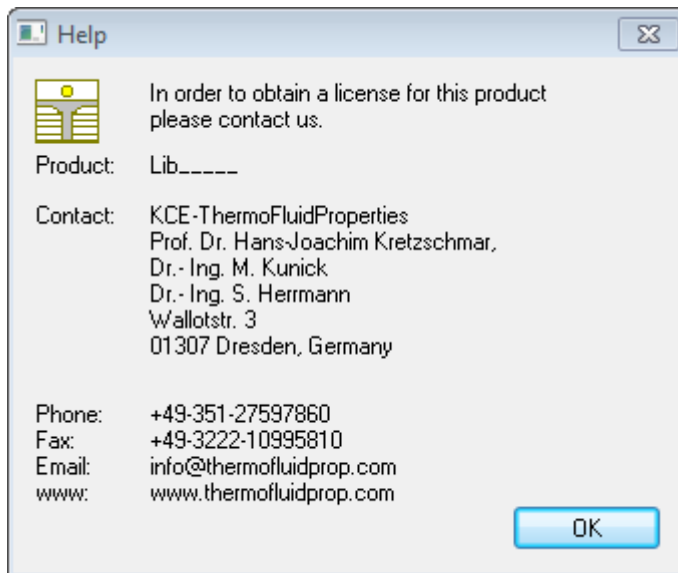
Figure 2.13: "Help" window

If you do not enter a valid license it is still possible to start Excel**®** by clicking "Cancel" twice. In this case, the LibIce property library will display the result "–11111111" for every calculation. The "License Information" window will appear every time you start Excel**®** unless you uninstall FluidEXL^Graphics according to the description in section 2.6 of this User's Guide.
Should you not wish to license the LibIce property library, you have to delete the files
    LibIce.dll
    LibIce.chm
in the installation folder of FluidEXL^Graphics (the standard being)
    C:\Program Files\FluidEXL_Graphics_Eng
using an appropriate program such as Explorer® or Norton Commander.

Note:

The product name "LibIce_ _ _ _ _ in Figure 2.12 and 2.13 stands for the LibIcerary you are installing. In this case it is the LibIce library.

2.4   Example calculation

Now we will calculate, step by step, the specific enthalpy *h* as a function of the pressure *p*, the temperature *t* and the vapor fraction *x* using FluidEXL^{Graphics}.

- Start Excel®
- Enter a value for *p* in bar in a cell

⇒ e. g.: Enter the value 10 into cell A2

- Enter a value for *t* in °C in a cell

   ⇒ e. g.: Enter the value -50 into cell B2

- Enter a value for *x* in kg/kg in a cell.
  In this example we want to calculate the specific enthalpy in the single phase region, we therefore need to insert the value -1 for *x*.

   ⇒ e. g.: Enter the value -1 into cell C2

- Click the cell in which the specific enthalpy *h* in kJ/kg is to be displayed.

   ⇒ e.g.: Click the D2 cell.

- Click "Calculate" in the menu bar of FluidEXL^{Graphics}.
  Now the "Insert Function" window appears (see Figure 2.14).
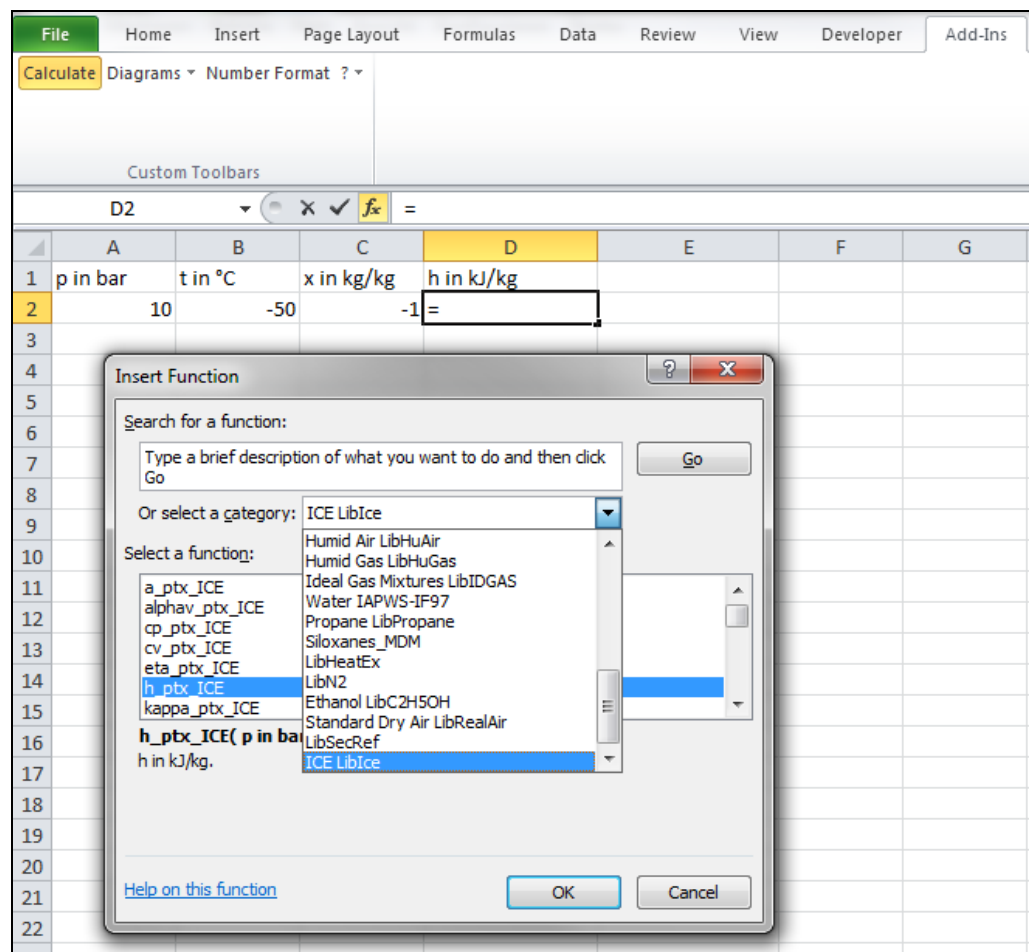
Figure 2.14: Choice of library and function name

- Search and click the "ICE LibIce" library under "Or select a category:" in the upper part of the window.

- Search and click the h_ptx_Ice function under "Select a function:" right below.

  Here it is possible to get more information on the range of validity, measuring units, error responses, etc. by clicking the "Help on this function" button.

- Click "OK".
  The window shown in Figure 2.15 will now appear.
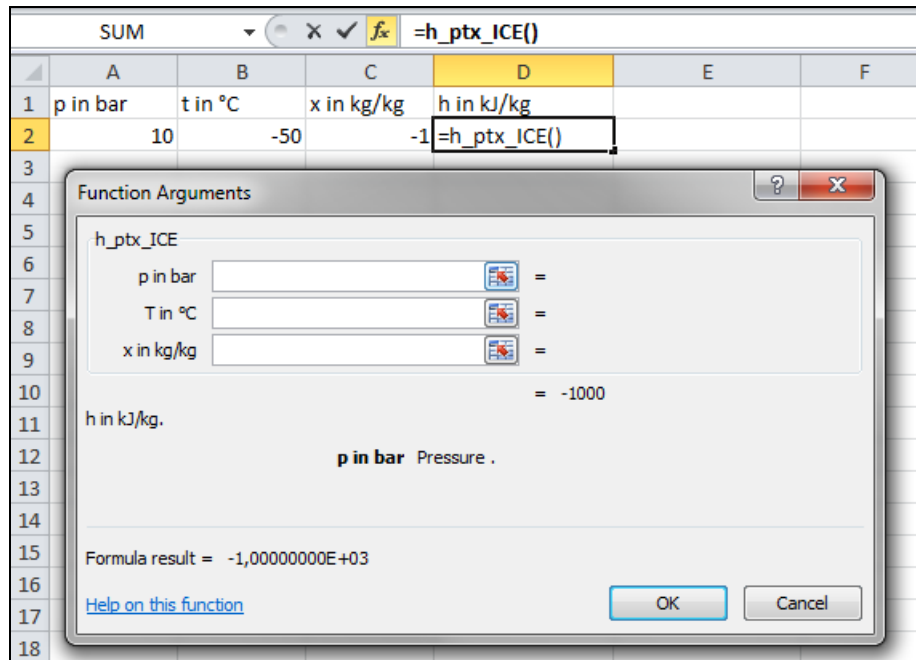
Figure 2.15: Input menu for the function

- Situate the cursor next to "p in bar" and enter the value for p by clicking the cell with the value for p, by entering the name of the cell with the value for p, or by entering the value for p directly.

  ⇒ e. g.: Type A2 into the window next to "p"

- Situate the cursor next to "T in °C" and enter the value for T by clicking the cell with the value for T, by entering the name of the cell with the value for T, or by entering the value for t directly.

  ⇒ e. g.: Click on the cell B2

- Situate the cursor next to "x in kg/kg" and enter the value for x by clicking the cell with the value for x, by entering the name of the cell with the value for x, or by entering the value for x directly.

  ⇒ e. g.: Type C2 into the window next to "x"

The window should now look like the following figure:
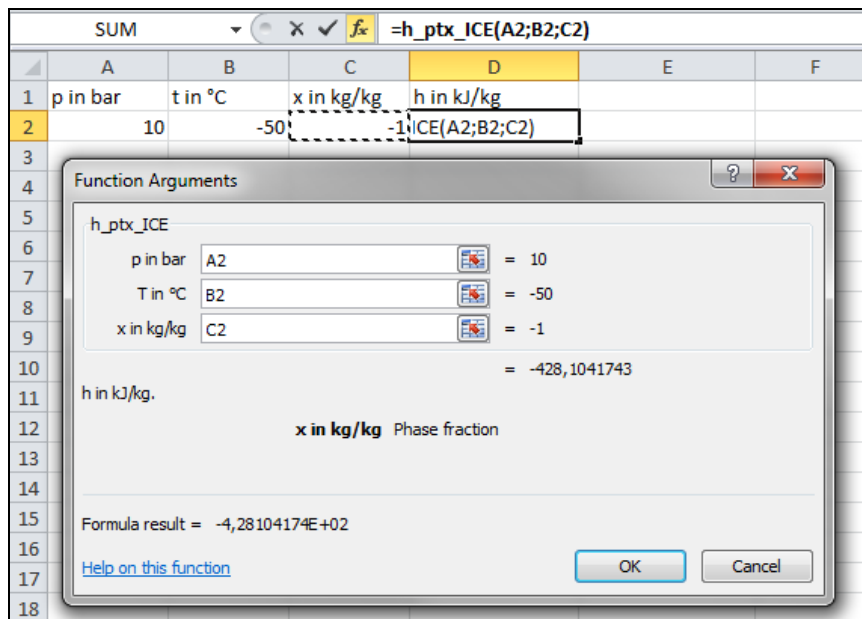
Figure 2.16: Input menu showing the result

- Click the "OK" button.
  The result for h in kJ/kg appears in the cell selected above.

  $\Rightarrow$ The result for h in our sample calculation here is: - 428.1041743 kJ/kg.

The calculation of $h = \mathrm{f}(p,t,x)$ has been carried out. You can now arbitrarily change the values for p, t or x in the appropriate cells. This shows that the Excel® data flow and the DLL calculations are working together successfully.

Note:

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

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

Number Formats

When using FluidEXL^{Graphics} you have the option of choosing special number formats in advance.
Changes can be made as follows:

- Click the cell or select and click on the cells you wish to format.
  (In empty cells the new format will be applied once a value has been entered.)

- Click "Number Format" in the FluidEXL^{Graphics} menu bar.

- Select the desired number format in the dialog box which appears:

  "STD – Standard":   Insignificant zeros behind the decimal point are not
                                 shown.

  "FIX – Fixed Number of Digits": All set decimal places are shown, including insignificant
                                 zeros.

  "SCI – Scientific Format":   Numbers are always shown in the exponential form with
                                 the set number of decimal places.

- Set the "Number of decimal places" by entering the number into the appropriate window.

- Confirm this by clicking the "OK" button.

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

STD	1.23
FIX	1.230
SCI	1.230E+00

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

2.5 The FluidEXL*Graphics* Help System

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

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

- Click "Calculate" in the FluidEXL*Graphics* menu bar.
- Click on the "LibICE" library under "Or select a category:" in the "Insert Function" window which will appear.
- Click the "Help on this function" button in the lower left-hand edge of the "Insert Function" window.
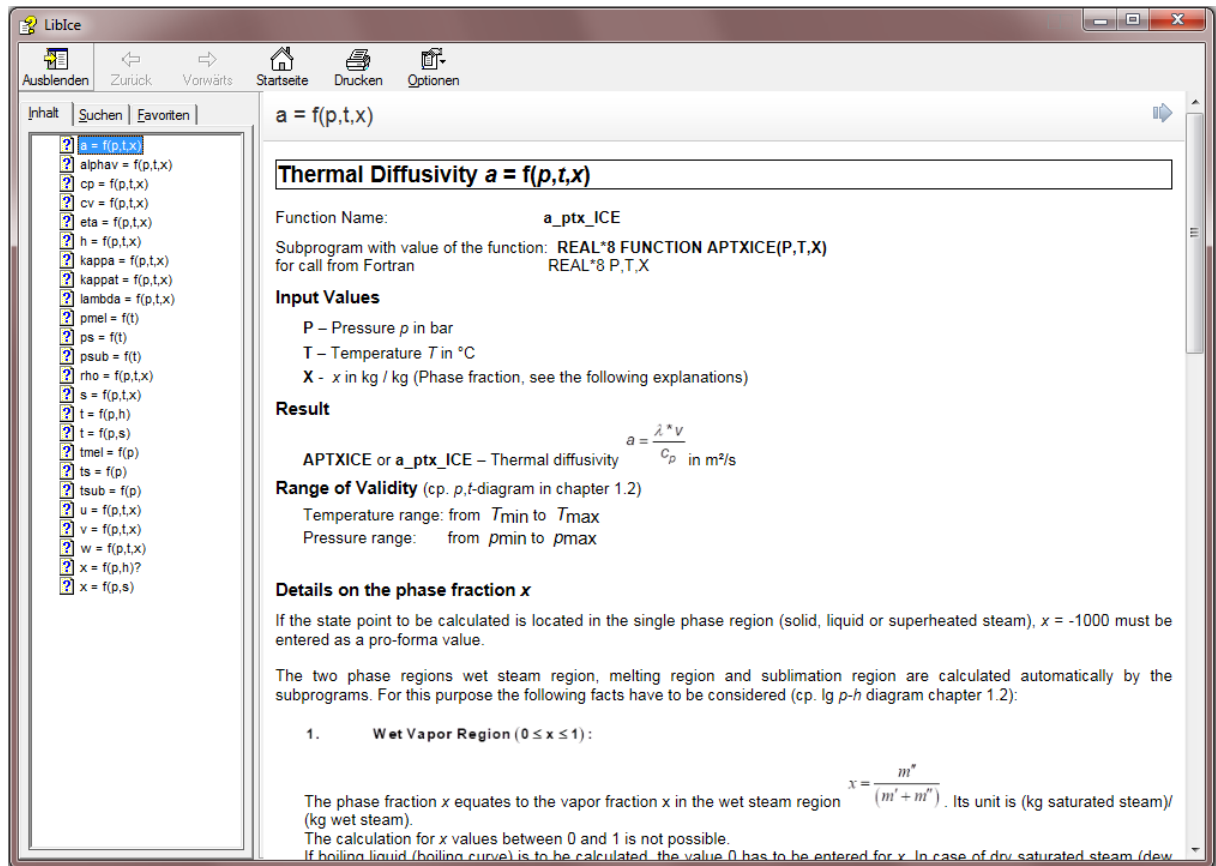
Figure 2.17: Help Window

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

C:\Program Files\FluidEXL_Graphics_Eng

to use the help system.

2.6 Removing FluidEXLGraphics

2.6.1 Removing LibIce Library

Should you wish to remove <u>only</u> the LibIce library, delete the files

LibIce.dll

LibIce.chm

in the directory selected for the installation of FluidEXL^{Graphics}, in the standard case,

C:\Program Files\FluidEXL_Graphics_Eng

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

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

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

- Click the "File" button in the upper left corner of Excel®

- Click on the "Options" button in the menu which appears
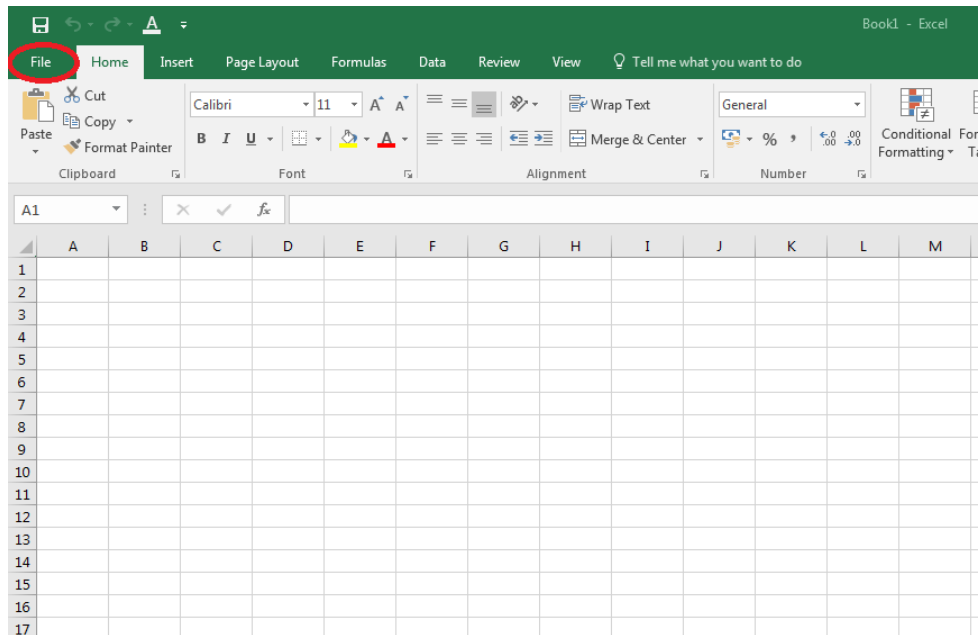
Figure 2.18: Unregistering FluidEXL^{Graphics} as Add-In in Excel® 2016
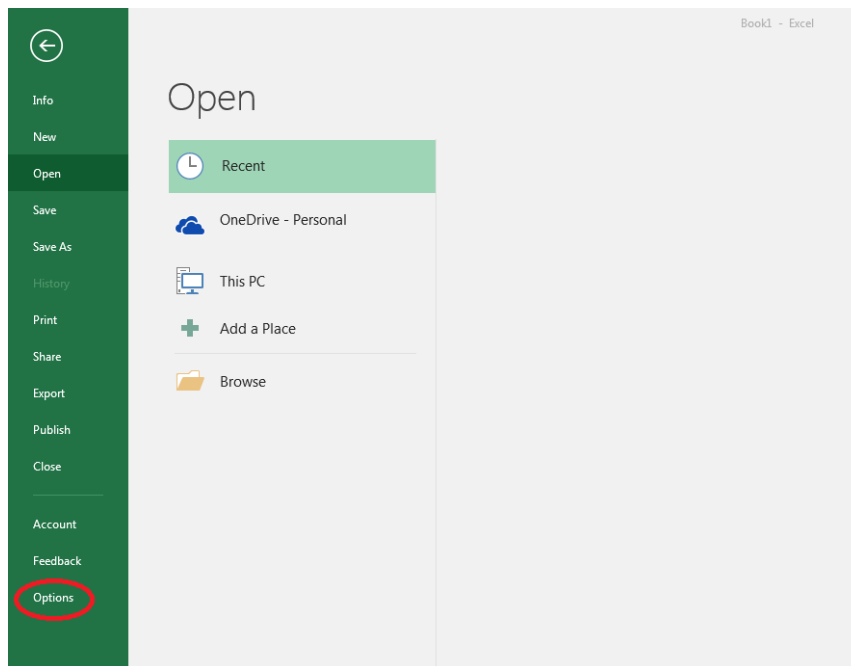
Figure 2.19 Unregistering FluidEXL*Graphics* as Add-In in Excel® 2016

- Click on "Add-Ins" in the next menu (Figure 2.20)
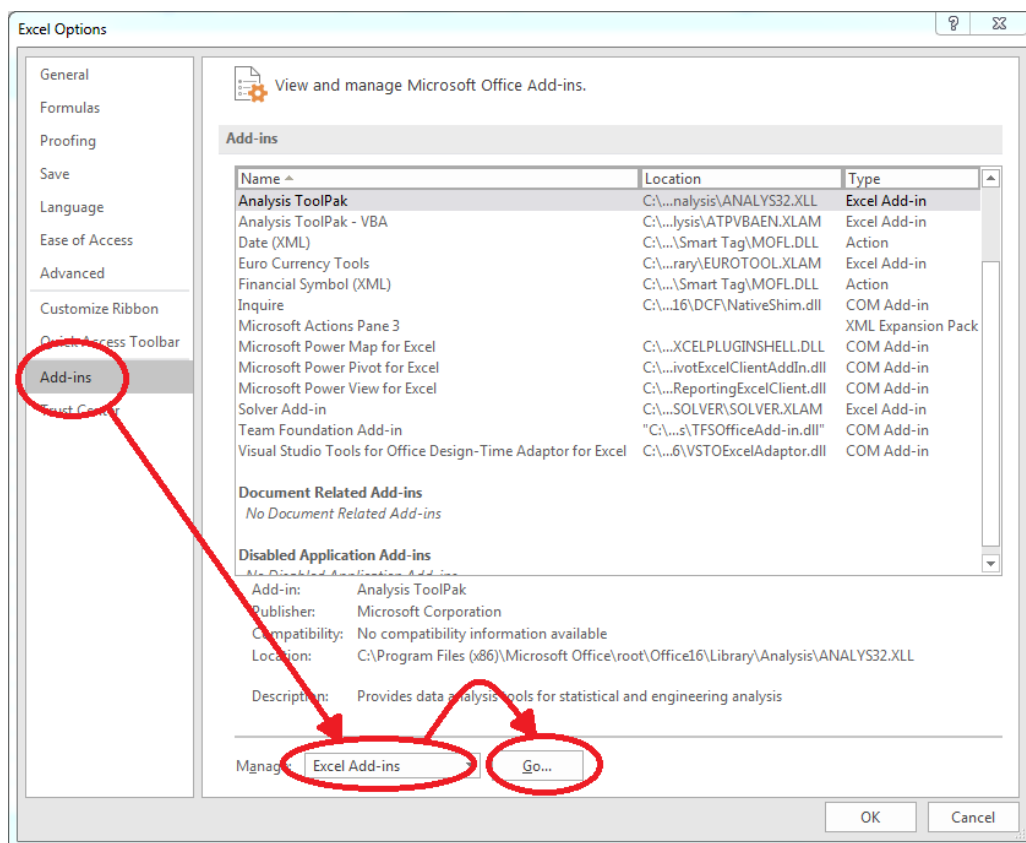
Figure 2.20: Dialog window "Add-Ins"

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

- Afterwards click the "Go…" button

- Remove the checkmark in front of
  "FluidEXL Graphics Eng"

in the window which now appears. Click the "OK" button to confirm your entry.
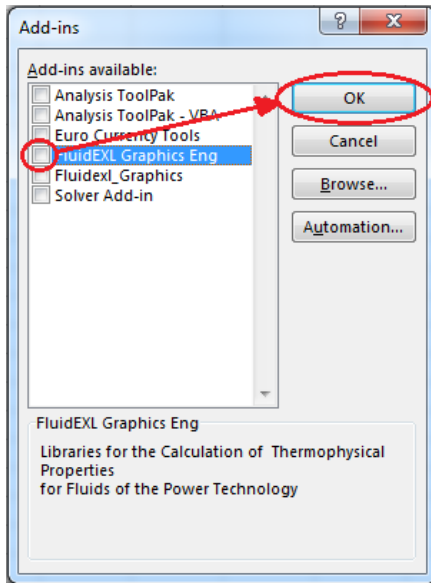
Figure 2.21: Dialog window "Add-Ins"

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

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

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

    "FluidEXL Graphics Eng"

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

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

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

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

Now FluidEXL^{Graphics} has been completely removed from your computer.

2.6.3 Unregistering and uninstalling FluidEXL^{Graphics} as Add-In in Excel®, versions 2003 or earlier

To remove FluidEXL^{Graphics} <u>completely,</u> proceed as follows: First the registration of

    FluidEXL_Graphics_Eng.xla

has to be cancelled in Excel®.

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

    "FluidEXL Graphics Eng"

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

If the FluidEXL^{Graphics} menu bar does not disappear, take the following steps:
Click "View" in the upper menu bar of Excel®, then "Toolbars" and then "Customize…" in the list box which appears.

"FluidEXL Graphics Eng"

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

Within the next step delete the files

LibIce.dll

LibIce.chm

in the directory selected for the installation of FluidEXL^{Graphics}, in the standard case,

C:\Program Files\FluidEXL_Graphics_Eng

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

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

"FluidEXL Graphics Eng"

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

Now FluidEXL^{Graphics} has been removed.

3. Program Documentation

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

Function Name: **a_ptx_ICE**

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

Input Values

P – Pressure p in bar

T – Temperature T in °C

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

Result

APTXICE or **a_ptx_ICE** – Thermal diffusivity $a = \dfrac{\lambda * v}{c_p}$ in m²/s

Range of Validity (cp. p,t-diagram in chapter 1.2)

Temperature range: from T_{min} to T_{max}
Pressure range: from p_{min} to p_{max}

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 = -1000 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 1.2):

1.   Wet Vapor Region $\left(0 \le x \le 1\right)$:

The phase fraction x equates to the vapor fraction x in the wet steam region $x = \dfrac{m''}{\left(m' + m''\right)}$. Its unit is

(kg 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_{max}
                            Pressure range from p_t to p_s (T_{max})

2.   Melting Region $\left(10 \le x \le 11\right)$:

The phase fraction x equates to the liquid fraction x in the melting region $x = 10 + \dfrac{m_{liq}}{\left(m_{ice} + m_{liq}\right)}$. Its unit

is (kg solidified liquid)/(kg melt), whereas melt is a mixture of melting ice and solidified 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 and
Solidification curve: Temperature range from T_t to $T_{mel}\,(p_{max})$
                             Pressure range from p_t to p_{max}

3.   Sublimation Region $\left(100 \le x \le 101\right)$:

The phase fraction x equates to the gas fraction x in the sublimation region $x = 100 + \dfrac{m_{gas}}{\left(m_{ice} + m_{gas}\right)}$. Its

unit is (kg desublimated gas)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating ice and desublimated gas.
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 <u>and</u> p = -1000 or the value given for p <u>and</u> t = -1000 and the value for x ($x = 100$ or $x = 101$). If p <u>and</u> t <u>and</u> 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 **APTXICE = –1000** or **a_ptx_ICE = –1000** for input values:

Single phase region:
   Solid, liquid, overheated steam (x = −1000):
   - at $p < p_{min}$ or $p > p_{max}$
   - at $T < T_{min}$ or $T > T_{max}$

Two phase regions:
   Wet steam region ($0 \le x \le 1$):
   - at $0 < x < 1$, i.e. calculation in the wet steam region not possible!
   - at $p = −1000$ and $T < T_t$ or $T > T_{max}$
   - at $t = −1000$ and $p < p_t$ or $p > p_s(T_{max})$
   - at $p < p_t$ or $p > p_s(T_{max})$
   - at $T < T_t$ or $T > T_{max}$

   Melting region ($10 \le x \le 11$):
   - at $10 < x < 11$, i.e. calculation in the melting region not possible!
   - at $p = −1000$ and $T > T_t$ or $T < T_{mel}(p_{max})$
   - at $t = −1000$ and $p < p_t$ or $p > p_{max}$
   - at $p < p_t$ or $p > p_{max}$
   - at $T > T_t$ or $T < T_{mel}(p_{max})$

   Sublimation region ($100 \le x \le 101$):
   - at $100 < x < 101$, i.e. calculation in the sublimation region not possible!
   - at $p = −1000$ and $T < T_{min}$ or $T > T_t$
   - at $t = −1000$ and $p < p_{min}$ or $p > p_t$
   - at $p < p_{min}$ or $p > p_t$
   - at $T < T_{min}$ or $T > T_t$

References: [1], [2], [3], [6], [7], [8]

Isobaric cubic expansion coefficient $\alpha_v = f(p,t,x)$

Function Name: **alphav_ptx_ICE**

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

Input Values

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

Result

> **ALPHAVPTXICE** or **alphav_ptx_ICE** – Isobaric cubic expansion coefficient α_v in 1/K

Range of Validity (cp. p,t-diagram in chapter 1.2)

> Temperature range: from T_{min} to T_{max}
>
> Pressure range: from p_{min} to p_{max}

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), $x = -1000$ 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 1.2):

> **1.**   **Wet Vapor Region $(0 \le x \le 1)$:**
>
> The phase fraction x equates to the vapor fraction x in the wet steam region $x = \dfrac{m''}{(m' + m'')}$. Its unit is
>
> (kg 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_{max}
>   Pressure range from p_t to p_s (T_{max})
>
> **2.**   **Melting Region $(10 \le x \le 11)$:**
>
> The phase fraction x equates to the liquid fraction x in the melting region $x = 10 + \dfrac{m_{liq}}{(m_{ice} + m_{liq})}$. Its unit
>
> is (kg solidified liquid)/(kg melt), whereas melt is a mixture of melting ice and solidified 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 and
> Solidification curve: Temperature range from T_t to T_{mel} (p_{max})
>   Pressure range from p_t to p_{max}

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

The phase fraction x equates to the gas fraction x in the sublimation region $x = 100 + \dfrac{m_{gas}}{\left(m_{ice} + m_{gas}\right)}$. Its

unit is (kg desublimated gas)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating ice and desublimated gas.
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 **ALPHAVPTXICE = –1000** or **alphav_ptx_ICE = –1000** for input values:

Single phase region:
Solid, liquid, overheated steam (x = −1000):
  - at $p < p_{min}$ or $p > p_{max}$
  - at $T < T_{min}$ or $T > T_{max}$

Two phase regions:
Wet steam region ($0 \le x \le 1$):
  - at $0 < x < 1$, i.e. calculation in the wet steam region not possible!
  - at $p = -1000$ and $T < T_t$ or $T > T_{max}$
  - at $t = -1000$ and $p < p_t$ or $p > p_s(T_{max})$
  - at $p < p_t$ or $p > p_s(T_{max})$
  - at $T < T_t$ or $T > T_{max}$

Melting region ($10 \le x \le 11$):
  - at $10 < x < 11$, i.e. calculation in the melting region not possible!
  - at $p = -1000$ and $T > T_t$ or $T < T_{mel}(p_{max})$
  - at $t = -1000$ and $p < p_t$ or $p > p_{max}$
  - at $p < p_t$ or $p > p_{max}$
  - at $T > T_t$ or $T < T_{mel}(p_{max})$

Sublimation region ($100 \le x \le 101$):
  - at $100 < x < 101$, i.e. calculation in the sublimation region not possible!
  - at $p = -1000$ and $T < T_{min}$ or $T > T_t$
  - at $t = -1000$ and $p < p_{min}$ or $p > p_t$
  - at $p < p_{min}$ or $p > p_t$
  - at $T < T_{min}$ or $T > T_t$

References: [1], [2], [6], [7], [8]

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

Function Name: **cp_ptx_ICE**

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

Input Values

P – Pressure p in bar

T – Temperature T in °C

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

Result

CPPTXICE or **cp_ptx_ICE** - specific isobaric heat capacity c_p in kJ/(kg K)

Range of Validity (cp. p,t-diagram in chapter 1.2)

Temperature range: from T_{min} to T_{max}
Pressure range: from p_{min} to p_{max}

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), $x = -1000$ 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 1.2):

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

The phase fraction x equates to the vapor fraction x in the wet steam region $x = \dfrac{m''}{(m' + m'')}$. Its unit is

(kg 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_{max}
                             Pressure range from p_t to p_s (T_{max})

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

The phase fraction x equates to the liquid fraction x in the melting region $x = 10 + \dfrac{m_{liq}}{(m_{ice} + m_{liq})}$. Its unit

is (kg solidified liquid)/(kg melt), whereas melt is a mixture of melting ice and solidified 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 and
Solidification curve: Temperature range from T_t to T_{mel} (p_{max})
                            Pressure range from p_t to p_{max}

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

The phase fraction x equates to the gas fraction x in the sublimation region $x = 100 + \dfrac{m_{gas}}{\left(m_{ice} + m_{gas}\right)}$. Its

unit is (kg desublimated gas)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating ice and desublimated gas.
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 <u>and</u> p = -1000 or the value given for p <u>and</u> t = -1000 and the value for x ($x = 100$ or $x = 101$). If p <u>and</u> t <u>and</u> 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 **CPPTXICE = –1000** or **cp_ptx_ICE = –1000** for input values:

Single phase region:
Solid, liquid, overheated steam (x = −1000):
  - at $p < p_{min}$ or $p > p_{max}$
  - at $T < T_{min}$ or $T > T_{max}$

Two phase regions:
Wet steam region ($0 \leq x \leq 1$):
  - at $0 < x < 1$, i.e. calculation in the wet steam region not possible!
  - at $p = -1000$ and $T < T_t$ or $T > T_{max}$
  - at $t = -1000$ and $p < p_t$ or $p > p_s(T_{max})$
  - at $p < p_t$ or $p > p_s(T_{max})$
  - at $T < T_t$ or $T > T_{max}$

Melting region ($10 \leq x \leq 11$):
  - at $10 < x < 11$, i.e. calculation in the melting region not possible!
  - at $p = -1000$ and $T > T_t$ or $T < T_{mel}(p_{max})$
  - at $t = -1000$ and $p < p_t$ or $p > p_{max}$
  - at $p < p_t$ or $p > p_{max}$
  - at $T > T_t$ or $T < T_{mel}(p_{max})$

Sublimation region ($100 \leq x \leq 101$):
  - at $100 < x < 101$, i.e. calculation in the sublimation region not possible!
  - at $p = -1000$ and $T < T_{min}$ or $T > T_t$
  - at $t = -1000$ and $p < p_{min}$ or $p > p_t$

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

  - at $T < T_{min}$ or $T > T_t$

References: [1], [2], [6], [7], [8]

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

Function Name: **cv_ptx_ICE**

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

Input Values

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

Result

> **CVPTXICE** or **cv_ptx_ICE** - specific isochoric heat capacity c_v in kJ/(kg K)

Range of Validity (cp. p,t-diagram in chapter 1.2)

> Temperature range: from T_{min} to T_{max}
> Pressure range: from p_{min} to p_{max}

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), $x = -1000$ 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 1.2):

> **1.**   **Wet Vapor Region $(0 \le x \le 1)$:**
>
> The phase fraction x equates to the vapor fraction x in the wet steam region $x = \dfrac{m''}{(m' + m'')}$. Its unit is
>
> (kg 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_{max}
>   Pressure range from p_t to p_s (T_{max})
>
> **2.**   **Melting Region $(10 \le x \le 11)$:**
>
> The phase fraction x equates to the liquid fraction x in the melting region $x = 10 + \dfrac{m_{liq}}{(m_{ice} + m_{liq})}$. Its unit
>
> is (kg solidified liquid)/(kg melt), whereas melt is a mixture of melting ice and solidified 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 and
> Solidification curve: Temperature range from T_t to T_{mel} (p_{max})
>   Pressure range from p_t to p_{max}

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

The phase fraction x equates to the gas fraction x in the sublimation region $x = 100 + \dfrac{m_{\text{gas}}}{\left(m_{\text{ice}} + m_{\text{gas}}\right)}$. Its

unit is (kg desublimated gas)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating ice and desublimated gas.

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 **CVPTXICE = –1000** or **cv_ptx_ICE = –1000** for input values:

Single phase region:
    Solid, liquid, overheated steam (x = −1000):
      - at $p < p_{\text{min}}$ or $p > p_{\text{max}}$
      - at $T < T_{\text{min}}$ or $T > T_{\text{max}}$

Two phase regions:
    Wet steam region ($0 \le x \le 1$):
      - at $0 < x < 1$, i.e. calculation in the wet steam region not possible!
      - at $p = −1000$ and $T < T_{\text{t}}$ or $T > T_{\text{max}}$
      - at $t = −1000$ and $p < p_{\text{t}}$ or $p > p_{\text{s}}(T_{\text{max}})$
      - at $p < p_{\text{t}}$ or $p > p_{\text{s}}(T_{\text{max}})$
      - at $T < T_{\text{t}}$ or $T > T_{\text{max}}$

    Melting region ($10 \le x \le 11$):
      - at $10 < x < 11$, i.e. calculation in the melting region not possible!
      - at $p = −1000$ and $T > T_{\text{t}}$ or $T < T_{\text{mel}}(p_{\text{max}})$
      - at $t = −1000$ and $p < p_{\text{t}}$ or $p > p_{\text{max}}$
      - at $p < p_{\text{t}}$ or $p > p_{\text{max}}$
      - at $T > T_{\text{t}}$ or $T < T_{\text{mel}}(p_{\text{max}})$

    Sublimation region ($100 \le x \le 101$):
      - at $100 < x < 101$, i.e. calculation in the sublimation region not possible!
      - at $p = −1000$ and $T < T_{\text{min}}$ or $T > T_{\text{t}}$
      - at $t = −1000$ and $p < p_{\text{min}}$ or $p > p_{\text{t}}$

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

      - at $T < T_{\text{min}}$ or $T > T_{\text{t}}$

References: [1], [2], [6], [7], [8]

Dynamic Viscosity η = f(p,t,x)

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

Input Values

P – Pressure p in bar

T – Temperature T in °C

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

Result

ETAPTXICE or **eta_ptx_ICE** – dynamic viscosity η in Pa s

Range of Validity (cp. p,t-diagram in chapter 1.2)

Temperature range: from T_{min} to T_{max}
Pressure range: from p_{min} to p_{max}

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 = -1000 must be entered as a pro-forma value. This function can only by used for liquid and steam region.

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 1.2):

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

The phase fraction x equates to the vapor fraction x in the wet steam region $x = \dfrac{m''}{(m' + m'')}$. Its unit is

(kg 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_{max}
                          Pressure range from p_t to p_s (T_{max})

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

The phase fraction x equates to the liquid fraction x in the melting region $x = 10 + \dfrac{m_{liq}}{(m_{ice} + m_{liq})}$. Its unit

is (kg solidified liquid)/(kg melt), whereas melt is a mixture of melting ice and solidified liquid.
The calculation for x values unequal to 11 is not possible .
For solidifying liquid (solidification curve) x = 11 has to be entered.
When calculating a solidifying liquid it 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 = 11). If p and t and x are entered as given values, the program tests whether p and t fulfil the melting pressure curve.

Solidification curve: Temperature range from T_t to T_{mel} (p_{max})
                        Pressure range from p_t to p_{max}

KCE-ThermoFluidProperties, Prof. Dr. Hans-Joachim Kretzschmar

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

The phase fraction x equates to the gas fraction x in the sublimation region $x = 100 + \dfrac{m_{\text{gas}}}{\left(m_{\text{ice}} + m_{\text{gas}}\right)}$. Its unit is (kg desublimated gas)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating ice and desublimated gas.

The calculation for x values unequal to 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 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 = 101). If p and t and x are entered as given values the program tests whether p and t fulfil the sublimation-pressure-curve.

Desublimation curve:　Temperatur range from T_{min} to T_{t}
　　　　　　　　　　　Pressure range from p_{min} to p_{t}

Results for wrong input values

Result **ETAPTXICE = –1000** or **eta_ptx_ICE = –1000** for input values:

Single phase region:
　Solid, liquid, overheated steam ($x = -1000$):
　　- at $p < p_{\text{min}}$ or $p > p_{\text{max}}$
　　- at $T < T_{\text{min}}$ or $T > T_{\text{max}}$

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 $T < T_{\text{t}}$ or $T > T_{\text{max}}$
　　- at $t = -1000$ and $p < p_{\text{t}}$ or $p > p_{\text{s}}(T_{\text{max}})$
　　- at $p < p_{\text{t}}$ or $p > p_{\text{s}}(T_{\text{max}})$
　　- at $T < T_{\text{t}}$ or $T > T_{\text{max}}$

　Melting region ($10 \leq x \leq 11$):
　　- at $x < 11$, i.e. calculation in the melting region not possible!
　　- at $p = -1000$ and $T > T_{\text{t}}$ or $T < T_{\text{mel}}(p_{\text{max}})$
　　- at $t = -1000$ and $p < p_{\text{t}}$ or $p > p_{\text{max}}$
　　- at $p < p_{\text{t}}$ or $p > p_{\text{max}}$
　　- at $T > T_{\text{t}}$ or $T < T_{\text{mel}}(p_{\text{max}})$

　Sublimation region ($100 \leq x \leq 101$):
　　- at $x < 101$, i.e. calculation in the sublimation region not possible!
　　- at $p = -1000$ and $T < T_{\text{min}}$ or $T > T_{\text{t}}$
　　- at $t = -1000$ and $p < p_{\text{min}}$ or $p > p_{\text{t}}$
　　- at $p < p_{\text{min}}$ or $p > p_{\text{t}}$
　　- at $T < T_{\text{min}}$ or $T > T_{\text{t}}$

References: [1], [2], [4], [6], [7], [8]

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

Function Name: **h_ptx_ICE**

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

Input Values

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

Result

> **HPTXICE** or **h_ptx_ICE** - specific enthalpy h in kJ/kg

Range of Validity (cp. p,t-diagram in chapter 1.2)

> Temperature range: from T_{min} to T_{max}
> Pressure range: from p_{min} to p_{max}

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= -1000 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 1.2):

> 1. **Wet Vapor Region** $(0 \leq x \leq 1)$:
>
> The phase fraction x equates to the vapor fraction x in the wet steam region $x = \dfrac{m''}{(m' + m'')}$. Its unit is
>
> (kg 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_{max}
>   Pressure range from p_t to p_s (T_{max})
>
> 2. **Melting Region** $(10 \leq x \leq 11)$:
>
> The phase fraction x equates to the liquid fraction x in the melting region $x = 10 + \dfrac{m_{liq}}{(m_{ice} + m_{liq})}$. Its unit
>
> is (kg solidified liquid)/(kg melt), whereas melt is a mixture of melting ice and solidified 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 and
Solidification curve: Temperature range from T_t to T_{mel} (p_{max})
                          Pressure range from p_t to p_{max}

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

The phase fraction x equates to the gas fraction x in the sublimation region $x = 100 + \dfrac{m_{gas}}{\left(m_{ice} + m_{gas}\right)}$. Its

unit is (kg desublimated gas)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating ice and desublimated gas. 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.

Melting and
Solidification curve: Temperatur range from T_{min} to T_t
                          Pressure range from p_{min} to p_t

Results for wrong input values

Result **HPTXICE = –1000** or **h_ptx_ICE = –1000** for input values:

Single phase region:
Solid, liquid, overheated steam ($x = -1000$):
- at $p < p_{min}$ or $p > p_{max}$
- at $T < T_{min}$ or $T > T_{max}$

Two phase regions:
Wet steam region ($0 \leq x \leq 1$):
- at $p = -1000$ and $T < T_t$ or $T > T_{max}$
- at $t = -1000$ and $p < p_t$ or $p > p_s(T_{max})$
- at $p < p_t$ or $p > p_s(T_{max})$
- at $T < T_t$ or $T > T_{max}$

Melting region ($10 \leq x \leq 11$):
- at $p = -1000$ and $T > T_t$ or $T < T_{mel}$ (p_{max})
- at $t = -1000$ and $p < p_t$ or $p > p_{max}$
- at $p < p_t$ or $p > p_{max}$
- at $T > T_t$ or $T < T_{mel}$ (p_{max})

Sublimation region ($100 \leq x \leq 101$):
- at $p = -1000$ and $T < T_{min}$ or $T > T_t$
- at $t = -1000$ and $p < p_{min}$ or $p > p_t$
- at $p < p_{min}$ or $p > p_t$
- at $T < T_{min}$ or $T > T_t$

References: [1], [2], [6], [7], [8]

Isentropic Exponent κ = f(p,t,x)

Function Name: **kappa_ptx_ICE**

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

Input Values

P – Pressure p in bar

T – Temperature T in °C

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

Result

KAPPAPTXICE or **kappa_ptx_ICE** – Isentropic exponent $\kappa = \dfrac{w^2}{p*v}$

Range of Validity (cp. p,t-diagram in chapter 1.2)

Temperature range: from T_{min} to T_{max}
Pressure range: from p_{min} to p_{max}

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), $x = -1000$ 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 1.2):

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

The phase fraction x equates to the vapor fraction x in the wet steam region $x = \dfrac{m''}{\left(m' + m''\right)}$. Its unit is

(kg 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_{max}
                              Pressure range from p_t to p_s (T_{max})

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

The phase fraction x equates to the liquid fraction x in the melting region $x = 10 + \dfrac{m_{liq}}{\left(m_{ice} + m_{liq}\right)}$. Its unit

is (kg solidified liquid)/(kg melt), whereas melt is a mixture of melting ice and solidified 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 and

Solidification curve: Temperature range from T_t to $T_{mel}(p_{max})$
                         Pressure range from p_t to p_{max}

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

The phase fraction x equates to the gas fraction x in the sublimation region $x = 100 + \dfrac{m_{gas}}{\left(m_{ice} + m_{gas}\right)}$. Its

unit is (kg desublimated gas)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating ice and desublimated gas.
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 **KAPPAPTXICE = –1000** or **kappa_ptx_ICE = –1000** for input values:

Single phase region:
   Solid, liquid, overheated steam (x = −1000):
   - at $p < p_{min}$ or $p > p_{max}$
   - at $T < T_{min}$ or $T > T_{max}$

Two phase regions:
   Wet steam region ($0 \leq x \leq 1$):
   - at $0 < x < 1$, i.e. calculation in the wet steam region not possible!
   - at $p = -1000$ and $T < T_t$ or $T > T_{max}$
   - at $t = -1000$ and $p < p_t$ or $p > p_s(T_{max})$
   - at $p < p_t$ or $p > p_s(T_{max})$
   - at $T < T_t$ or $T > T_{max}$

   Melting region ($10 \leq x \leq 11$):
   - at $10 < x < 11$, i.e. calculation in the melting region not possible!
   - at $p = -1000$ and $T > T_t$ or $T < T_{mel}(p_{max})$
   - at $t = -1000$ and $p < p_t$ or $p > p_{max}$
   - at $p < p_t$ or $p > p_{max}$
   - at $T > T_t$ or $T < T_{mel}(p_{max})$

   Sublimation region ($100 \leq x \leq 101$):
   - at $100 < x < 101$, i.e. calculation in the sublimation region not possible!
   - at $p = -1000$ and $T < T_{min}$ or $T > T_t$
   - at $t = -1000$ and $p < p_{min}$ or $p > p_t$
   - at $p < p_{min}$ or $p > p_t$
   - at $T < T_{min}$ or $T > T_t$

References: [1], [2], [6], [7], [8]

Isothermal compressibility κ_t = f(p,t,x)

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

Input Values

   P – Pressure p in bar

   T – Temperature T in °C

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

Result

   KAPPATPTXICE or **kappaT_ptx_ICE** – Isothermal compressibility κ_T in 1/kPa

Range of Validity (cp. p,t-diagram in chapter 1.2)

   Temperature range: from T_{min} to T_{max}
   Pressure range: from p_{min} to p_{max}

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 = -1000 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 1.2):

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

   The phase fraction x equates to the vapor fraction x in the wet steam region $x = \dfrac{m''}{(m' + m'')}$. Its unit is

   (kg 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_{max}
                                 Pressure range from p_t to p_s (T_{max})

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

   The phase fraction x equates to the liquid fraction x in the melting region $x = 10 + \dfrac{m_{liq}}{(m_{ice} + m_{liq})}$. Its unit

   is (kg solidified liquid)/(kg melt), whereas melt is a mixture of melting ice and solidified 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 and
   Solidification curve: Temperature range from T_t to T_{mel} (p_{max})
                                Pressure range from p_t to p_{max}

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

The phase fraction x equates to the gas fraction x in the sublimation region $x = 100 + \dfrac{m_{\text{gas}}}{\left(m_{\text{ice}} + m_{\text{gas}}\right)}$. Its

unit is (kg desublimated gas)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating ice and desublimated gas.

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 <u>and</u> p = -1000 or the value given for p <u>and</u> t = -1000 and the value for x ($x = 100$ or $x = 101$). If p <u>and</u> t <u>and</u> 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 **KAPPATPTXICE = –1000** or **kappaT_ptx_ICE = –1000** for input values:

Single phase region:
    Solid, liquid, overheated steam (x = −1000):
     - at $p < p_{\min}$ or $p > p_{\max}$
     - at $T < T_{\min}$ or $T > T_{\max}$

Two phase regions:
    Wet steam region ($0 \le x \le 1$):
     - at $0 < x < 1$, i.e. calculation in the wet steam region not possible!
     - at $p = −1000$ and $T < T_{\text{t}}$ or $T > T_{\max}$
     - at $t = −1000$ and $p < p_{\text{t}}$ or $p > p_{\text{s}}(T_{\max})$
     - at $p < p_{\text{t}}$ or $p > p_{\text{s}}(T_{\max})$
     - at $T < T_{\text{t}}$ or $T > T_{\max}$

    Melting region ($10 \le x \le 11$):
     - at $10 < x < 11$, i.e. calculation in the melting region not possible!
     - at $p = −1000$ and $T > T_{\text{t}}$ or $T < T_{\text{mel}}(p_{\max})$
     - at $t = −1000$ and $p < p_{\text{t}}$ or $p > p_{\max}$
     - at $p < p_{\text{t}}$ or $p > p_{\max}$
     - at $T > T_{\text{t}}$ or $T < T_{\text{mel}}(p_{\max})$

    Sublimation region ($100 \le x \le 101$):
     - at $100 < x < 101$, i.e. calculation in the sublimation region not possible!
     - at $p = −1000$ and $T < T_{\min}$ or $T > T_{\text{t}}$
     - at $t = −1000$ and $p < p_{\min}$ or $p > p_{\text{t}}$

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

     - at $T < T_{\min}$ or $T > T_{\text{t}}$

References: [1], [2], [6], [7], [8]

Thermal Conductivity λ = f(p,t,x)

Function Name: **lambda_ptx_ICE**

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

Input Values

P – Pressure p in bar

T – Temperature T in °C

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

Result

LAMBDAPTXICE or **lambda_ptx_ICE** – Thermal conductivity λ in W/(m K)

Range of Validity (cp. p,t-diagram in chapter 1.2)

Temperature range: from T_{min} to T_{max}
Pressure range: from p_{min} to p_{max}

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 = -1000 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 1.2):

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

The phase fraction x equates to the vapor fraction x in the wet steam region $x = \dfrac{m''}{(m' + m'')}$. Its unit is

(kg 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_{max}
Pressure range from p_t to p_s (T_{max})

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

The phase fraction x equates to the liquid fraction x in the melting region $x = 10 + \dfrac{m_{liq}}{(m_{ice} + m_{liq})}$. Its unit

is (kg solidified liquid)/(kg melt), whereas melt is a mixture of melting ice and solidified 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 and

Solidification curve: Temperature range from T_t to $T_{mel}(p_{max})$
                           Pressure range from p_t to p_{max}

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

The phase fraction x equates to the gas fraction x in the sublimation region $x = 100 + \dfrac{m_{gas}}{\left(m_{ice} + m_{gas}\right)}$. Its

unit is (kg desublimated gas)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating ice and desublimated gas.
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 **LAMBDAPTXICE = –1000** or **lambda_ptx_ICE = –1000** for input values:

Single phase region:
     Solid, liquid, overheated steam (x = −1000):
       - at $p < p_{min}$ or $p > p_{max}$
       - at $T < T_{min}$ or $T > T_{max}$

Two phase regions:
     Wet steam region ($0 \leq x \leq 1$):
       - at $0 < x < 1$, i.e. calculation in the wet steam region not possible!
       - at $p = −1000$ and $T < T_t$ or $T > T_{max}$
       - at $t = −1000$ and $p < p_t$ or $p > p_s(T_{max})$
       - at $p < p_t$ or $p > p_s(T_{max})$
       - at $T < T_t$ or $T > T_{max}$

     Melting region ($10 \leq x \leq 11$):
       - at $10 < x < 11$, i.e. calculation in the melting region not possible!
       - at $p = −1000$ and $T > T_t$ or $T < T_{mel}(p_{max})$
       - at $t = −1000$ and $p < p_t$ or $p > p_{max}$
       - at $p < p_t$ or $p > p_{max}$
       - at $T > T_t$ or $T < T_{mel}(p_{max})$

     Sublimation region ($100 \leq x \leq 101$):
       - at $100 < x < 101$, i.e. calculation in the sublimation region not possible!
       - at $p = −1000$ and $T < T_{min}$ or $T > T_t$
       - at $t = −1000$ and $p < p_{min}$ or $p > p_t$
       - at $p < p_{min}$ or $p > p_t$
       - at $T < T_{min}$ or $T > T_t$

References: [1], [2], [3], [6], [7], [8]

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

Function Name: **pmel_t_08_ICE**

Subprogram with value of the function: **REAL*8 FUNCTION PMEL_T_08_ICE (T)**
for call from Fortran   REAL*8 T

Input Values

T - Temperature T in °C

Result

PMEL_T_08_ICE or **pmel_t_08_ICE** – Melting pressure p_{mel} in bar

Range of Validity (cp. p,t-diagram in chapter 1.2)

Temperature range from T_t to $T_{mel} (p_{max})$

Results for wrong input values

Result **PMEL_T_08_ICE = –1000** or **pmel_t_08_ICE = –1000** for input values:

- at $T > T_t$ or $T < T_{mel} (p_{max})$

References: [8]

Vapor Pressure p_s = f(t)

Function Name: **ps_t_97_ICE**

Subprogram with value of the function: **REAL*8 FUNCTION PS_T_97_ICE (T)**
for call from Fortran REAL*8 T

Input Values

    T - Temperature T in °C

Result

    PS_T_97_ICE or **ps_t_97_ICE** – vapor pressure p_s in bar

Range of Validity (cp. p,t-diagram in chapter 1.2)

    Temperature range: from T_t to T_c

Results for wrong input values

Result **PS_T_97_ICE = –1000** or **ps_t_97_ICE = –1000** for input values:

- at $T < T_t$ or $T > T_c$

References: [1], [2]

Sublimation Pressure p_{sub} = f(t)

Function Name: **psub_t_08_ICE**

Subprogram with value of the function: **REAL*8 FUNCTION PSUB_T_08_ICE (T)**
for call from Fortran   REAL*8 T

Input Values

    T - Temperature T in °C

Result

    PSUB_T_08_ICE or **psub_t_08_ICE** – Sublimation pressure p_{sub} in bar

Range of Validity (cp. p,t-diagram in chapter 1.2)

    Temperature range: from T_{min} to T_t

Results for wrong input values

Result **PSUB_T_08_ICE = –1000** or **psub_t_08_ICE = –1000** for input values:

- at $T < T_{min}$ or $T > T_t$

References: [8]

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

Function Name: **rho_ptx_ICE**

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

Input Values

    P – Pressure p in bar

    T – Temperature T in °C

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

Result

    RHOPTXICE or **rho_ptx_ICE** - Density ρ in kg/m^3

Range of Validity (cp. p,t-diagram in chapter 1.2)

    Temperature range: from T_{min} to T_{max}
    Pressure range: from p_{min} to p_{max}

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= -1000 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 1.2):

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

The phase fraction x equates to the vapor fraction x in the wet steam region $x = \dfrac{m''}{(m' + m'')}$. Its unit is (kg 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_{max}
                                  Pressure range from p_t to p_s (T_{max})

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

The phase fraction x equates to the liquid fraction x in the melting region $x = 10 + \dfrac{m_{liq}}{(m_{ice} + m_{liq})}$. Its unit is (kg solidified liquid)/(kg melt), whereas melt is a mixture of melting ice and solidified 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 and
Solidification curve: Temperature range from T_t to $T_{mel}\,(p_{max})$
Pressure range from p_t to p_{max}

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

The phase fraction x equates to the gas fraction x in the sublimation region $x = 100 + \dfrac{m_{gas}}{\left(m_{ice} + m_{gas}\right)}$. Its

unit is (kg desublimated gas)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating ice and desublimated gas. 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.

Melting and
Solidification curve: Temperatur range from T_{min} to T_t
Pressure range from p_{min} to p_t

Results for wrong input values

Result **RHOPTXICE = −1000** or **rho_ptx_ICE = −1000** for input values:

Single phase region:
 Solid, liquid, overheated steam ($x = -1000$):
  - at $p < p_{min}$ or $p > p_{max}$
  - at $T < T_{min}$ or $T > T_{max}$

Two phase regions:
 Wet steam region ($0 \leq x \leq 1$):
  - at $p = -1000$ and $T < T_t$ or $T > T_{max}$
  - at $t = -1000$ and $p < p_t$ or $p > p_s(T_{max})$
  - at $p < p_t$ or $p > p_s(T_{max})$
  - at $T < T_t$ or $T > T_{max}$

 Melting region ($10 \leq x \leq 11$):
  - at $p = -1000$ and $T > T_t$ or $T < T_{mel}\,(p_{max})$
  - at $t = -1000$ and $p < p_t$ or $p > p_{max}$
  - at $p < p_t$ or $p > p_{max}$
  - at $T > T_t$ or $T < T_{mel}\,(p_{max})$

 Sublimation region ($100 \leq x \leq 101$):
  - at $p = -1000$ and $T < T_{min}$ or $T > T_t$
  - at $t = -1000$ and $p < p_{min}$ or $p > p_t$
  - at $p < p_{min}$ or $p > p_t$
  - at $T < T_{min}$ or $T > T_t$

References: [1], [2], [6], [7], [8]

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

Function Name: **s_ptx_ICE**

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

Input Values

P – Pressure p in bar

T – Temperature T in °C

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

Result

SPTXICE or **s_ptx_ICE** - Specific entropy s in kJ/(kg K)

Range of Validity (cp. p,t-diagram in chapter 1.2)

Temperature range: from T_{min} to T_{max}
Pressure range: from p_{min} to p_{max}

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= -1000 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 1.2):

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

The phase fraction x equates to the vapor fraction x in the wet steam region $x = \dfrac{m''}{\left(m' + m''\right)}$. Its unit is

(kg 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_{max}
                            Pressure range from p_t to p_s (T_{max})

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

The phase fraction x equates to the liquid fraction x in the melting region $x = 10 + \dfrac{m_{liq}}{\left(m_{ice} + m_{liq}\right)}$. Its unit

is (kg solidified liquid)/(kg melt), whereas melt is a mixture of melting ice and solidified 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 and
Solidification curve: Temperature range from T_t to T_{mel} (p_{max})
                           Pressure range from p_t to p_{max}

3.   Sublimation Region $(100 \le \mathbf{x} \le 101)$:

The phase fraction x equates to the gas fraction x in the sublimation region $x = 100 + \dfrac{m_{gas}}{\left(m_{ice} + m_{gas} \right)}$. Its

unit is (kg desublimated gas)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating ice and desublimated gas. 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.

Melting and
Solidification curve: Temperatur range from T_{min} to T_t
                           Pressure range from p_{min} to p_t

Results for wrong input values

Result **SPTXICE = –1000** or **s_ptx_ICE = –1000** for input values:

Single phase region:
   Solid, liquid, overheated steam ($x = -1000$):
      - at $p < p_{min}$ or $p > p_{max}$
      - at $T < T_{min}$ or $T > T_{max}$

Two phase regions:
   Wet steam region ($0 \le x \le 1$):
      - at $p = -1000$ and $T < T_t$ or $T > T_{max}$
      - at $t = -1000$ and $p < p_t$ or $p > p_s(T_{max})$
      - at $p < p_t$ or $p > p_s(T_{max})$
      - at $T < T_t$ or $T > T_{max}$

   Melting region ($10 \le x \le 11$):
      - at $p = -1000$ and $T > T_t$ or $T < T_{mel}(p_{max})$
      - at $t = -1000$ and $p < p_t$ or $p > p_{max}$
      - at $p < p_t$ or $p > p_{max}$
      - at $T > T_t$ or $T < T_{mel}(p_{max})$

   Sublimation region ($100 \le x \le 101$):
      - at $p = -1000$ and $T < T_{min}$ or $T > T_t$
      - at $t = -1000$ and $p < p_{min}$ or $p > p_t$
      - at $p < p_{min}$ or $p > p_t$
      - at $T < T_{min}$ or $T > T_t$

References: [1], [2], [6], [7], [8]

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

Function Name: **t_ph_ICE**

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

Input Values

   P – Pressure p in bar

   H - Specific enthalpy h in kJ/kg

Result

   TPHICE or **t_ph_ICE** – Temperature t in °C

Range of Validity (cp. p,t-diagram in chapter 1.2)

   Pressure range: from p_{min} to p_{max}
   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 1.2) are calculated automatically by the subprograms. After that, the calculation is realized for the certain region.

Results for wrong input values

Result **TPHICE = –1000** or **t_ph_ICE = –1000** for input values:

Single phase region:
   Solid, liquid, overheated steam:
      - at $p < p_{min}$ or $p > p_{max}$
      - at calculation result $T < T_{min}$ or $T > T_{max}$ or $T > T_{mel} (p_{max})$ when calculating melting region

Two phase regions:
   Wet steam region:
      - at $p < p_t$ or $p > p_s(T_{max})$
      - at calculation result $T < T_t$ or $T > T_{max}$

   Melting region:
      - at $p < p_t$ or $p > p_{max}$
      - at calculation result $T > T_t$ or $T < T_{mel} (p_{max})$

   Sublimation region:
      - at $p < p_{min}$ or $p > p_t$
      - at calculation result $T < T_{min}$ or $T > T_t$

References: [1], [2], [6], [7], [8]

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

Function Name: **t_ps_ICE**

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

Input Values

P – Pressure p in bar

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

Result

TPSICE or **t_ps_ICE** – Temperature t in °C

Range of Validity (cp. p,t-diagram in chapter 1.2)

Pressure range: from p_{min} to p_{max}
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 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 the two phase region. The two phase regions wet steam region, melting region and sublimation region (cp. lg p,h-diagram chapter 1.2) are calculated automatically by the subprograms. After that, the calculation is realized for the certain region.

Results for wrong input values

Result **TPSICE = –1000** or **t_ps_ICE = –1000** for input values:

Single phase region:
    Solid, liquid, overheated steam:
      - at $p < p_{min}$ or $p > p_{max}$
      - at calculation result $T < T_{min}$ or $T > T_{max}$ or $T > T_{mel}(p_{max})$ when calculating melting region

Two phase regions:
    Wet steam region:
      - at $p < p_t$ or $p > p_s(T_{max})$
      - at calculation result $T < T_t$ or $T > T_{max}$

    Melting region:
      - at $p < p_t$ or $p > p_{max}$
      - at calculation result $T > T_t$ or $T < T_{mel}(p_{max})$

    Sublimation region:
      - at $p < p_{min}$ or $p > p_t$
      - at calculation result $T < T_{mel}(p_{max})$ or $T > T_t$

References: [1], [2], [6], [7], [8]

Melting Temperature t_{mel} = f(p)

Function Name: **tmel_p_08_ICE**

Subprogram with value of the function: **REAL*8 FUNCTION TMEL_P_08_ICE (P)**
for call from Fortran   REAL*8 P

Input Values

  P – Pressure p in bar

Result

  TMEL_P_08_ICE or **tmel_p_08_ICE** – Melting temperature t_{mel} in °C

Range of Validity (cp. p,t-diagram in chapter 1.2)

  Pressure range: from p_t to p_{max}

Results for wrong input values

Result **TMELICE = –1000** or **tmel_p_ICE = –1000** for input values:

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

References: [8]

Saturation Temperature $t_s = f(p)$

Function Name: **ts_p_97_ICE**

Subprogram with value of the function: **REAL*8 FUNCTION TS_P_97_ICE (P)**
for call from Fortran REAL*8 P

Input Values

P – Pressure p in bar

Result

TS_P_97_ICE or **ts_p_97_ICE** – Saturation temperature t_s in °C

Range of Validity (cp. p,t-diagram in chapter 1.2)

Pressure range: from p_t to p_c

Results for wrong input values

Result **TS_P_97_ICE = –1000** or **ts_p_97_ICE = –1000** for input values:

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

References: [1], [2]

Sublimation Temperature t_{sub} = f(p)

Function Name: **tsub_p_08_ICE**

Subprogram with value of the function: **REAL*8 FUNCTION TSUB_P_08_ICE (P)**
for call from Fortran   REAL*8 P

Input Values

P – Pressure p in bar

Result

TSUB_P_08_ICE or **tsub_p_08_ICE** – Sublimation temperature t_{sub} in °C

Range of Validity (cp. p,t-diagram in chapter 1.2)

Pressure range: from p_{min} to p_t

Results for wrong input values

Result **TSUB_P_08_ICE = –1000** or **tsub_p_08_ICE = –1000** for input values:

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

References: [8]

Specific inner energy u = f(*p*,*t*,*x*)

Function Name: **u_ptx_ICE**

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

Input Values

P – Pressure *p* in bar

T – Temperature *T* in °C

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

Result

UPTXICE or **u_ptx_ICE** – Specific inner energy *u* in kJ/kg

Range of Validity (cp. *p*,*t*-diagram in chapter 1.2)

Temperature range: from T_{min} to T_{max}
Pressure range: from p_{min} to p_{max}

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= -1000 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 1.2):

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

The phase fraction *x* equates to the vapor fraction x in the wet steam region $x = \dfrac{m''}{(m' + m'')}$. Its unit is

(kg 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* <u>and</u> *p* = -1000 or the given value for *p* <u>and</u> *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* <u>and</u> *t* <u>and</u> *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_{max}
                                  Pressure range from p_t to p_s (T_{max})

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

The phase fraction *x* equates to the liquid fraction *x* in the melting region $x = 10 + \dfrac{m_{liq}}{(m_{ice} + m_{liq})}$. Its unit

is (kg solidified liquid)/(kg melt), whereas melt is a mixture of melting ice and solidified 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* <u>and</u> p = -1000 or the value given for *p* <u>and</u> t = -1000 and the value for *x* (*x* = 10 or *x* = 11). If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program tests whether *p* and *t* fulfil the melting pressure curve.

Melting and
Solidification curve: Temperature range from T_t to T_{mel} (p_{max})
                         Pressure range from p_t to p_{max}

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

The phase fraction x equates to the gas fraction x in the sublimation region $x = 100 + \dfrac{m_{gas}}{\left(m_{ice} + m_{gas} \right)}$. Its

unit is (kg desublimated gas)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating ice and desublimated gas. 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* <u>and</u> p = -1000 or the value given for *p* <u>and</u> t = -1000 and the value for x (x = 100 or x = 101). If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values the program tests whether *p* and *t* fulfil the sublimation-pressure-curve.

Melting and
Solidification curve: Temperatur range from T_{min} to T_t
                         Pressure range from p_{min} to p_t

Results for wrong input values

Result **UPTXICE = –1000** or **u_ptx_ICE = –1000** for input values:

Single phase region:
    Solid, liquid, overheated steam ($x = -1000$):
      - at $p < p_{min}$ or $p > p_{max}$
      - at $T < T_{min}$ or $T > T_{max}$

Two phase regions:
    Wet steam region ($0 \le x \le 1$):
      - at $p = -1000$ and $T < T_t$ or $T > T_{max}$
      - at $t = -1000$ and $p < p_t$ or $p > p_s(T_{max})$
      - at $p < p_t$ or $p > p_s(T_{max})$
      - at $T < T_t$ or $T > T_{max}$

    Melting region ($10 \le x \le 11$):
      - at $p = -1000$ and $T > T_t$ or $T < T_{mel}(p_{max})$
      - at $t = -1000$ and $p < p_t$ or $p > p_{max}$
      - at $p < p_t$ or $p > p_{max}$
      - at $T > T_t$ or $T < T_{mel}(p_{max})$

    Sublimation region ($100 \le x \le 101$):
      - at $p = -1000$ and $T < T_{min}$ or $T > T_t$
      - at $t = -1000$ and $p < p_{min}$ or $p > p_t$
      - at $p < p_{min}$ or $p > p_t$
      - at $T < T_{min}$ or $T > T_t$

References: [1], [2], [6], [7], [8]

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

Function Name: **v_ptx_ICE**

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

Input Values

P – Pressure p in bar

T – Temperature T in °C

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

Result

VPTXICE or **v_ptx_ICE** – Specific volume v in m^3/kg

Range of Validity (cp. p,t-diagram in chapter 1.2)

Temperature range: from T_{min} to T_{max}
Pressure range: from p_{min} to p_{max}

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= -1000 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 1.2):

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

The phase fraction x equates to the vapor fraction x in the wet steam region $x = \dfrac{m''}{(m' + m'')}$. Its unit is

(kg 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_{max}
Pressure range from p_t to p_s (T_{max})

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

The phase fraction x equates to the liquid fraction x in the melting region $x = 10 + \dfrac{m_{liq}}{(m_{ice} + m_{liq})}$. Its unit

is (kg solidified liquid)/(kg melt), whereas melt is a mixture of melting ice and solidified 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 and
Solidification curve: Temperature range from T_t to T_{mel} (p_{max})
                       Pressure range from p_t to p_{max}

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

The phase fraction x equates to the gas fraction x in the sublimation region $x = 100 + \dfrac{m_{gas}}{\left(m_{ice} + m_{gas}\right)}$. Its

unit is (kg desublimated gas)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating ice and desublimated gas. 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* <u>and</u> p = -1000 or the value given for *p* <u>and</u> t = -1000 and the value for x (x = 100 or x = 101). If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values the program tests whether *p* and *t* fulfil the sublimation-pressure-curve.

Melting and
Solidification curve: Temperatur range from T_{min} to T_t
                       Pressure range from p_{min} to p_t

Results for wrong input values

Result **VPTXICE = –1000** or **v_ptx_ICE = –1000** for input values:

Single phase region:
   Solid, liquid, overheated steam ($x = -1000$):
     - at $p < p_{min}$ or $p > p_{max}$
     - at $T < T_{min}$ or $T > T_{max}$

Two phase regions:
   Wet steam region ($0 \le x \le 1$):
     - at $p = -1000$ and $T < T_t$ or $T > T_{max}$
     - at $t = -1000$ and $p < p_t$ or $p > p_s(T_{max})$
     - at $p < p_t$ or $p > p_s(T_{max})$
     - at $T < T_t$ or $T > T_{max}$

   Melting region ($10 \le x \le 11$):
     - at $p = -1000$ and $T > T_t$ or $T < T_{mel}(p_{max})$
     - at $t = -1000$ and $p < p_t$ or $p > p_{max}$
     - at $p < p_t$ or $p > p_{max}$
     - at $T > T_t$ or $T < T_{mel}(p_{max})$

   Sublimation region ($100 \le x \le 101$):
     - at $p = -1000$ and $T < T_{min}$ or $T > T_t$
     - at $t = -1000$ and $p < p_{min}$ or $p > p_t$
     - at $p < p_{min}$ or $p > p_t$
     - at $T < T_{min}$ or $T > T_t$

References: [1], [2], [6], [7], [8]

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

Function Name: **w_ptx_ICE**

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

Input Values

P – Pressure p in bar

T – Temperature T in °C

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

Result

WPTXICE or **w_ptx_ICE** – Speed of sound w in m/s

Range Range of Validity (cp. p,t-diagram in chapter 1.2)

Temperature range: from T_{min} to T_{max}
Pressure range: from p_{min} to p_{max}

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), $x = -1000$ 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 1.2):

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

The phase fraction x equates to the vapor fraction x in the wet steam region $x = \dfrac{m''}{(m' + m'')}$. Its unit is

(kg 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 <u>and</u> p = -1000 or the given value for p <u>and</u> 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 <u>and</u> t <u>and</u> 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_{max}
Pressure range from p_t to p_s (T_{max})

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

The phase fraction x equates to the liquid fraction x in the melting region $x = 10 + \dfrac{m_{liq}}{(m_{ice} + m_{liq})}$. Its unit

is (kg solidified liquid)/(kg melt), whereas melt is a mixture of melting ice and solidified 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 <u>and</u> p = -1000 or the value given for p <u>and</u> t = -1000 and the value for x (x = 10 or x = 11). If p <u>and</u> t <u>and</u> x are entered as given values, the program tests whether p and t fulfil the melting pressure curve.

Melting and
Solidification curve: Temperature range from T_t to T_{mel} (p_{max})
Pressure range from p_t to p_{max}

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

The phase fraction x equates to the gas fraction x in the sublimation region $x = 100 + \dfrac{m_{gas}}{\left(m_{ice} + m_{gas}\right)}$. Its

unit is (kg desublimated gas)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimating ice and desublimated gas.
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 <u>and</u> p = -1000 or the value given for p <u>and</u> t = -1000 and the value for x ($x = 100$ or $x = 101$). If p <u>and</u> t <u>and</u> 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 **WPTXICE = −1000** or **w_ptx_ICE = −1000** for input values:

Single phase region:
   Solid, liquid, overheated steam (x = −1000):
    - at $p < p_{min}$ or $p > p_{max}$
    - at $T < T_{min}$ or $T > T_{max}$

Two phase regions:
   Wet steam region (0 ≤ x ≤ 1):
    - at $0 < x < 1$, i.e. calculation in the wet steam region not possible!
    - at $p = -1000$ and $T < T_t$ or $T > T_{max}$
    - at $t = -1000$ and $p < p_t$ or $p > p_s(T_{max})$
    - at $p < p_t$ or $p > p_s(T_{max})$
    - at $T < T_t$ or $T > T_{max}$

   Melting region (10 ≤ x ≤ 11):
    - at $10 < x < 11$, i.e. calculation in the melting region not possible!
    - at $p = -1000$ and $T > T_t$ or $T < T_{mel}(p_{max})$
    - at $t = -1000$ and $p < p_t$ or $p > p_{max}$
    - at $p < p_t$ or $p > p_{max}$
    - at $T > T_t$ or $T < T_{mel}(p_{max})$

   Sublimation region (100 ≤ x ≤ 101):
    - at $100 < x < 101$, i.e. calculation in the sublimation region not possible!
    - at $p = -1000$ and $T < T_{min}$ or $T > T_t$
    - at $t = -1000$ and $p < p_{min}$ or $p > p_t$

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

    - at $T < T_{min}$ or $T > T_t$

References: [1], [2], [6], [7], [8]

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

Function Name: **x_ph_ICE**

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

Input Values

P – Pressure p in bar

H - Specific enthalpy h in kJ/kg

Result

XPHICE, **X** or **x_ph_ICE** – Vapor fraction x in (kg saturated steam/kg wet steam)

Range of Validity (cp. p,t-diagram in chapter 1.2)

Pressure range: from p_t to $p_s(T_{max})$ for wet steam region
                    from p_t to p_{max} for melting region
                    from p_{min} to p_t for sublimation region

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 1.2). 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 **XPHICE = –1** or **x_ph_ICE = –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 1.2).

Two phase regions:
    Wet steam region ($0 \leq x \leq 1$):
      - at $p < p_t$ or $p > p_s(T_{max})$
      - at calculation result $T < T_t$ or $T > T_{max}$

    Melting region ($10 \leq x \leq 11$):
      - at $p < p_t$ or $p > p_{max}$
      - at calculation result $T > T_t$ or $T < T_{mel}(p_{max})$

    Sublimation region ($100 \leq x \leq 101$):
      - at $p < p_{min}$ or $p > p_t$
      - at calculation result $T < T_{min}$ or $T > T_t$

References: [1], [2], [6], [7], [8]

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

Function Name: **x_ps_ICE**

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

Input Values

P – Pressure p in bar

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

Result

XPSICE or **x_ps_ICE** – Vapor fraction x in (kg saturated steam/kg wet steam)

Range of Validity (cp. p,t-diagram in chapter 1.2)

Pressure range: from p_t to $p_s(T_{max})$ for wet steam region
                    from p_t to p_{max} for melting region
                    from p_{min} to p_t for sublimation region

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 1.2). 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 **XPSICE = –1** or **x_ps_ICE = –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 1.2).

Two phase regions:
    Wet steam region ($0 \leq x \leq 1$):
      - at $p < p_t$ or $p > p_s(T_{max})$
      - at calculation result $T < T_t$ or $T > T_{max}$

    Melting region ($10 \leq x \leq 11$):
      - at $p < p_t$ or $p > p_{max}$
      - at calculation result $T > T_t$ or $T < T_{mel}(p_{max})$

    Sublimation region ($100 \leq x \leq 101$):
      - at $p < p_{min}$ or $p > p_t$
      - at calculation result $T < T_{min}$ or $T > T_t$

References: [1], [2], [6], [7], [8]

KCE-ThermoFluidProperties
www.thermofluidprop.com

KCE ThermoFluidProperties

Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

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 Thermo-dynamic 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

$C_2H_6O_2$	Ethylene glycol
$C_3H_8O_2$	Propylene glycol
C_2H_5OH	Ethanol
CH_3OH	Methanol
$C_3H_8O_3$	Glycerol
K_2CO_3	Potassium carbonate
$CaCl_2$	Calcium chloride
$MgCl_2$	Magnesium chloride
NaCl	Sodium chloride
$C_2H_3KO_2$	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 $C_{14}H_{42}O_5Si_6$ **Library LibMD4M**

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Nitrogen and Oxygen

**Libraries
LibN2 and LibO2**

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

Hydrogen

Library LibH2

Formulation of
Leachman et al. (2009)

Helium

Library LibHe

Formulation of
Arp et al. (1998)

Hydrocarbons

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

Isopentane C_5H_{12} **Library LibC5H12_Iso**

Neopentane C_5H_{12} **Library LibC5H12_Neo**

Isohexane C_6H_{14} **Library LibC6H14**

Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

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

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

Hydrogen sulfide H_2S **Library LibH2S**

Nitrous oxide N_2O **Library LibN2O**

Sulfur dioxide SO_2 **Library LibSO2**

Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

KCE

ThermoFluidProperties
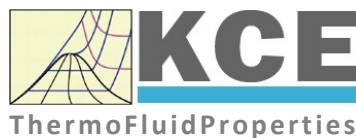
For more information please contact:

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

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

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 v
- 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.

www.thermofluidprop.com

KCE-ThermoFluidProperties
www.thermofluidprop.com

KCE ThermoFluidProperties

Hochschule Zittau/Görlitz
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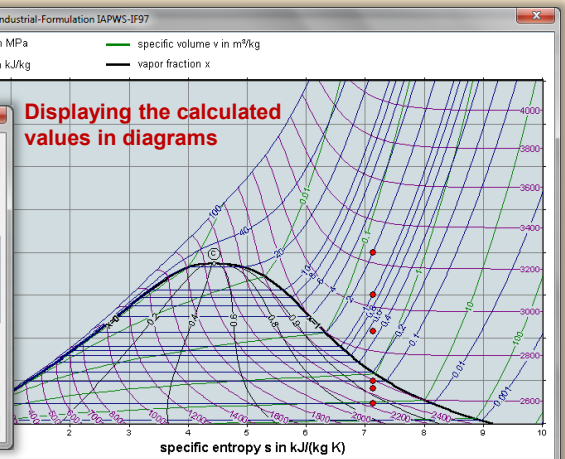## Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Add-In FluidEXL^{Graphics} for Excel®
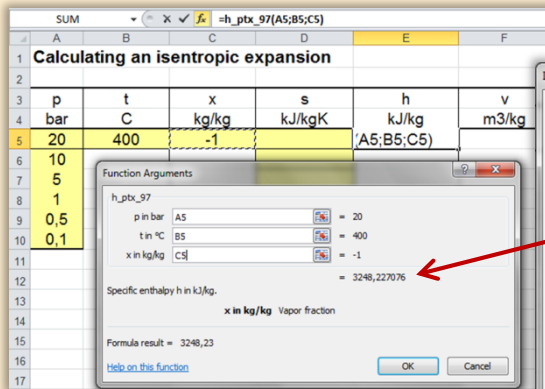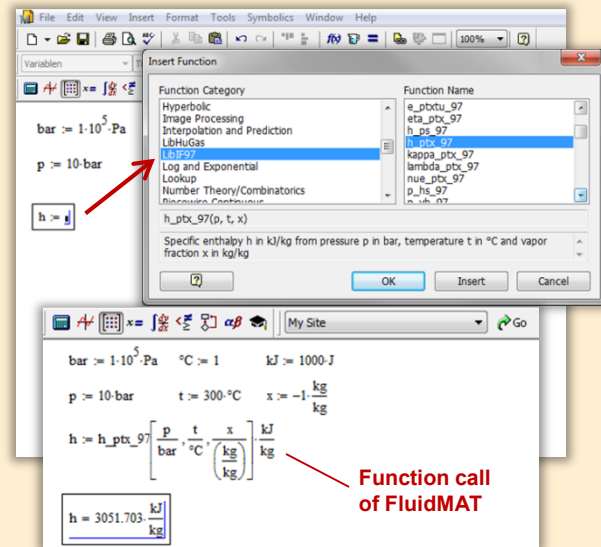
Choosing a property library and a function
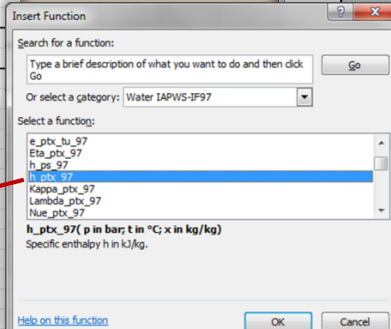
Displaying the calculated values in diagrams
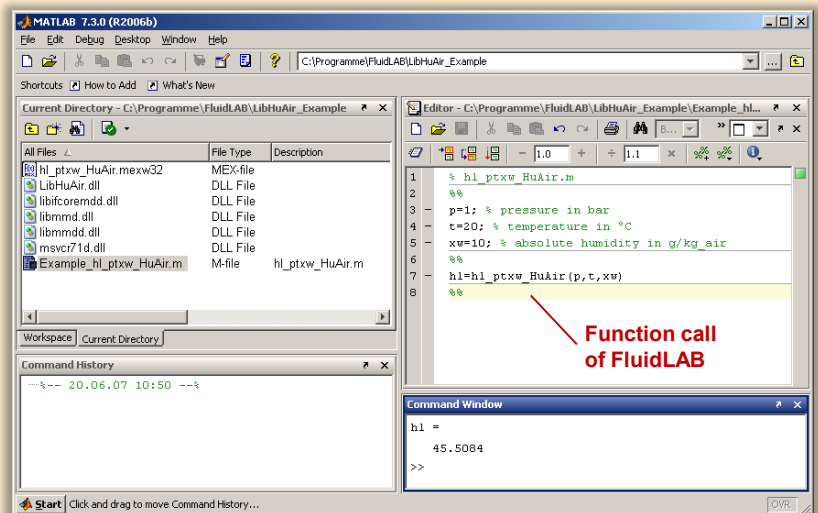
Menu for the input of given property values

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

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

Function call of FluidMAT

Add-On FluidLAB for MATLAB® and SIMULINK®

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

Function call of FluidLAB

Add-On FluidVIEW for LabVIEW™

The property functions can be calculated in LabVIEW™.
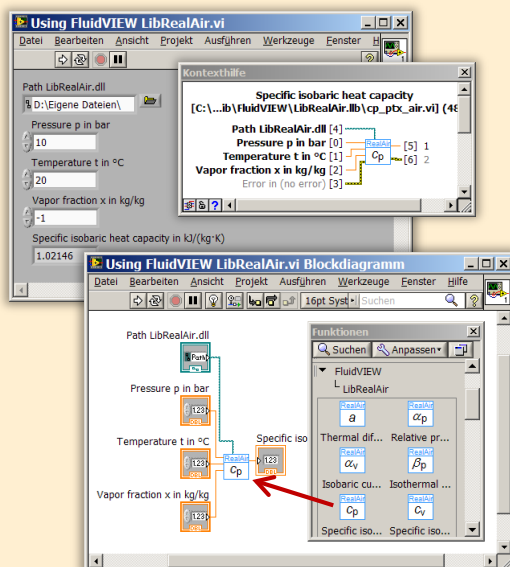
Add-On FluidDYM for DYMOLA® (Modelica) and SimulationX®

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

5. References

[1]   IAPWS:
        Revised Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic
        Properties of Water and Steam IAPWS-IF97.
        Available at the IAPWS Website http://www.iapws.org

[2]   Wagner, W.; Kretzschmar, H.-J.:
        International Steam Tables.
        Springer-Verlag, Berlin (2008)
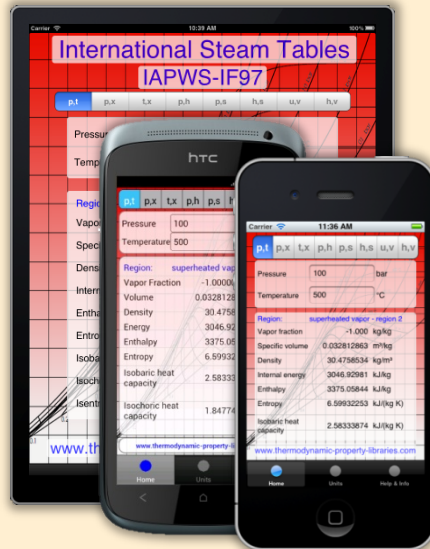
[3]   IAPWS:
        Release on the IAPWS Formulation 2011 for the Thermal Conductivity of Ordinary
        Water Substance.
        Available at the IAPWS Website http://www.iapws.org.

[4]   IAPWS:
        Release on the IAPWS Formulation 2008 for the Viscosity of Ordinary Water
        Substance.
        IAPWS Secretariat, Dooley, B., EPRI, Palo Alto CA, (1997)

[5]   IAPWS:
        Revised Release on the IAPWS Formulation 1995 for the Thermodynamic Properties
        of Ordinary Water Substance for General and Scientific Use.
        Available at the IAPWS Website http://www.iapws.org

[6]   IAPWS:
        Revised Release on the Equation of State 2006 for H2O Ice Ih.
        Available at the IAPWS Website http://www.iapws.org

[7]   IAPWS:
        Revised Release 2008 on the Pressure along the Melting and Sublimation Curves of
        Ordinary0020Water Substance.
        Available at the IAPWS Website http://www.iapws.org

6. Satisfied Customers

Period from 2018 to 2022

The following companies and institutions use the property libraries:

- FluidEXL^{Graphics} for Excel$^®$ incl. VBA

- FluidLAB for MATLAB$^®$ and Simulink

- FluidMAT for Mathcad$^®$

- FluidPRIME for Mathcad Prime$^®$

- FluidEES for Engineering Equation Solver$^®$ EES

- FluidDYM for Dymola$^®$ (Modelica) and SimulationX$^®$

- FluidVIEW for LabVIEW^{TM}

- FluidPYT for Python

- FluidJAVA for Java

- DLLs for Windows Applications

- Shared Objects for Linux

- Shared Objects for macOS.

2022

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

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

2021

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

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

2020

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

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

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

2019

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

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

2018

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

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