Property Library for Nitrogen

FluidEXL *Graphics*
with LibN2
for Excel®

Prof. Dr. Hans-Joachim Kretzschmar
Prof. Dr. Matthias Kunick
Dr. Sebastian Herrmann
M.Eng Martin Suender
Ines Jaehne
Guido Keuchel

Software for the Calculation of the Properties of Nitrogen

Including DLL and Add-In for Excel®

FluidEXL *Graphics* LibN2

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_LibN2_x64.zip

including the following folders an files:

\FLUFT\

\Formulation97\

FluidEXL_Graphics_LibN2_Docu_Eng.pdf

FluidEXL_Graphics_Eng.xla

LC.dll

LibN2.dll

LibN2.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_LibN2.zip

including the following folders and files:

\FLUFT\

\Formulation97\

FluidEXL_Graphics_LibN2_Docu_Eng.pdf

FluidEXL_Graphics_Eng.xla

LC.dll

LibN2.dll

LibN2.chm.

1. Program Functions

1.1 Range of Validity

The calculation of nitrogen is described in detail in the publications by *SPAN et al.* [2] and *LEMMON et al.* [1]. It includes temperatures from 63.151 K (-209.999°C) to 1000 K (726.85°C) and pressures from 0.00001 bar to 22000 bar. Important bulks are given in Table 1.1.

Table 1.1: Range of validity

Bulks	Abbreviations	Values and Units
pressures: minimal	P_{min}	$1 \cdot 10^{-5}$ bar
at triple point	P_t	0.12532 bar
at critical point	P_c	33.958 bar
maximal	P_{max}	22000 bar
temperatures: minimal	$T_{min} = T_t$	-209.999°C
at critical point	T_c	-146.958 °C
maximal	T_{max}	726.85°C

Figure 1.1 shows the entire range of validity for the equation in a *p,t*-diagram and Figure 1.2 in a *p,v*-diagram.
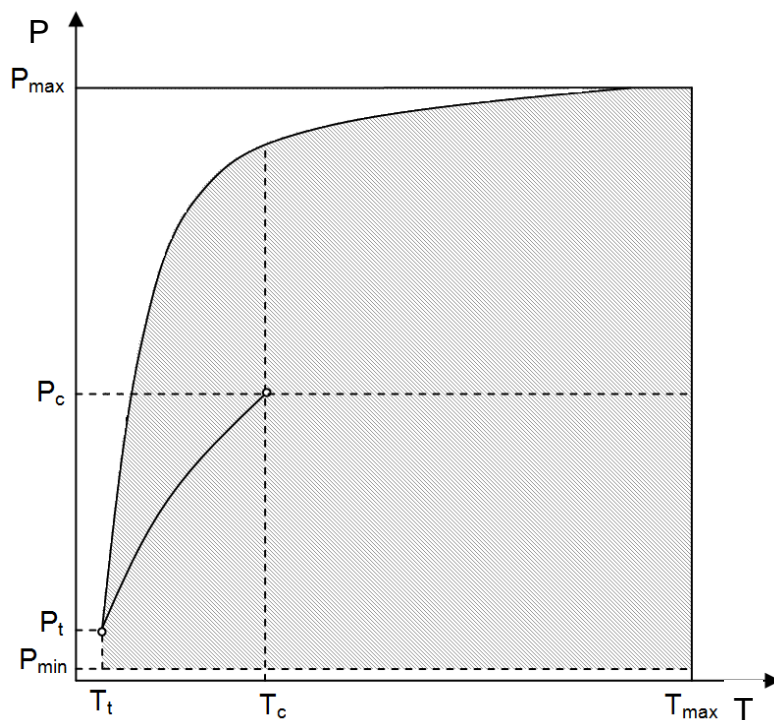
Figure 1.1: Entire range of validity of SPAN in a *p,t*-diagram

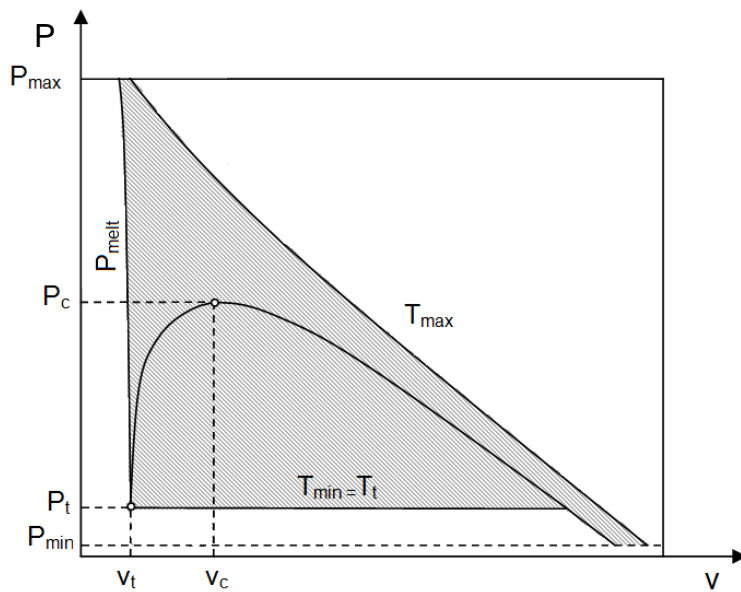**Figure 1.2: Entire range of validity of SPAN in a *p,v*-diagram**

The sub-programs of the LibN2 DLL and the functions of the Add-In FluidEXL*Graphics* for Excel are listed in the following section.

All sub-programs and functions can be applied in the entire range of validity of the LibN2. The call of the necessary equation of state for each calculation region will be realized within the program.

1.2 Functions

Functional Dependence	Function Name	Call from DLL LibN2, Result as Parameter	Property or Function	Unit of the Result
$a = f(p,t,x)$	a_ptx_N2	= APTXN2(P,T,X)	Thermal diffusivity	m^2/s
$\alpha_P = f(p,t,x)$	alphap_ptx_N2	= ALPHAPPTXN2(P,T,X)	Relative pressure coefficient	1/K
$\alpha_v = f(p,t,x)$	alphav_ptx_N2	= ALPHAVPTXN2(P,T,X)	Isobaric cubic expansion coefficient	1/K
$\beta_P = f(p,t,x)$	betap_ptx_N2	= BETAPPTXN2(P,T,X)	Isothermal stress coefficient	kg/m^3
$c_p = f(p,t,x)$	cp_ptx_N2	= CPPTXN2(P,T,X)	Specific isobaric heat capacity	$kJ/(kg \cdot K)$
$c_v = f(p,t,x)$	cv_ptx_N2	= CVPTXN2(P,T,X)	Specific isochoric heat capacity	$kJ/(kg \cdot K)$
$\eta = f(p,t,x)$	eta_ptx_N2	= ETAPTXN2(P,T,X)	Dynamic viscosity	$Pa \cdot s = kg/(m \cdot s)$
$h = f(p,t,x)$	h_ptx_N2	= HPTXN2(P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p,t,x)$	kappa_ptx_N2	= KAPPAPTXN2(P,T,X)	Isentropic exponent	-
$\kappa_T = f(p,t,x)$	kappat_ptx_N2	= KAPPATPTXN2(P,T,X)	Isothermal compressibility	1/kPa
$\lambda = f(p,t,x)$	lambda_ptx_N2	= LAMPTXN2(P,T,X)	Thermal conductivity	$W/(m \cdot K)$
$v = f(p,t,x)$	ny_ptx_N2	= NYPTXN2(P,T,X)	Kinematic viscosity	m^2/s
$p_{mel} = f(t)$	p_mel_t_N2	= PMELTN2(T)	Melting pressure	bar
$Pr = f(p,t,x)$	Pr_ptx_N2	= PRPTXN2(P,T,X)	Prandtl number	-
$p_s = f(t)$	ps_t_N2	= PSTN2(T)	Vapor pressure	bar
$\rho = f(p,t,x)$	rho_ptx_N2	= RHOPTXN2(P,T,X)	Density	kg / m^3
$s = f(p,t,x)$	s_ptx_N2	= SPTXN2(P,T,X)	Specific entropy	$kJ/(kg \cdot K)$
$t_{mel} = f(p)$	t_mel_p_N2	= TMELPN2(P)	Melting temperature	°C

Functional Dependence	Function Name	Call from DLL LibN2, Result as Parameter	Property or Function	Unit of the Result
$t = \mathrm{f}(p,h)$	t_ph_N2	= TPHN2(P,H)	Backward function: Temperature from pressure and enthalpy	°C
$t_\mathrm{s} = \mathrm{f}(p)$	ts_p_N2	= TSPN2(P)	Saturation temperature	°C
$t = \mathrm{f}(p,s)$	t_ps_N2	= TPSN2(P,S)	Backward function: Temperature from pressure and entropy	°C
$u = \mathrm{f}(p,t,x)$	u_ptx_N2	= UPTXN2(P,T,X)	Specific internal energy	kJ/kg
$v = \mathrm{f}(p,t,x)$	v_ptx_N2	= VPTXN2(P,T,X)	Specific volume	m^3/kg
$w = \mathrm{f}(p,t,x)$	w_ptx_N2	= WPTXN2(P,T,X)	Speed of sound	m/s
$x = \mathrm{f}(p,h)$	x_ph_N2	= XPHN2(P,H)	Backward function: Vapor fraction from pressure and enthalpy	kg/kg
$x = \mathrm{f}(p,s)$	x_ps_N2	= XPSN2(P,S)	Backward function: Vapor fraction from pressure and entropy	kg/kg
$z = \mathrm{f}(p,t,x)$	z_ptx_N2	= zPTXN2(P,T,X)	Compression factor	-

Units: *t* in °C

                 p in bar

                 x in kg saturated steam/kg wet steam

Range of validity of the LibN2

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the vapor fraction *x* and on the calculation of wet steam

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

<u>Single-phase region</u>

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

<u>Wet-steam region</u>

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for *x*. It is adequate to enter either the given value for t <u>and</u> p = –1000, or the given value for p <u>and</u> t = –1000, plus the value for *x* between 0 and 1. When *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Wet steam region of the LibN2: t_t = 63.151 K (-209.999°C)   ... p_t = 0.12523 bar   (t – triple point)

                                            t_C = 126.192 K (-146.958°C)   ... p_C = 33.958   bar   (c – critical point))

Note.

If the calculation results in –1000, the values entered represent a state point beyond the range of validity of SPAN. For further information on each function and its range of validity see Chapter 3. The same information may also be accessed via the online help pages.

1.3 Thermodynamic Diagrams

The properties of nitrogen are calculated with FluidEXL^{Graphics} including the LibN2 property library. The results are shown in the following thermodynamic diagrams:

- *lgp,lgv*-diagram   Figure 1.3

- *lgp,h*-diagram   Figure 1.4

- *T,s*-diagram   Figure 1.5
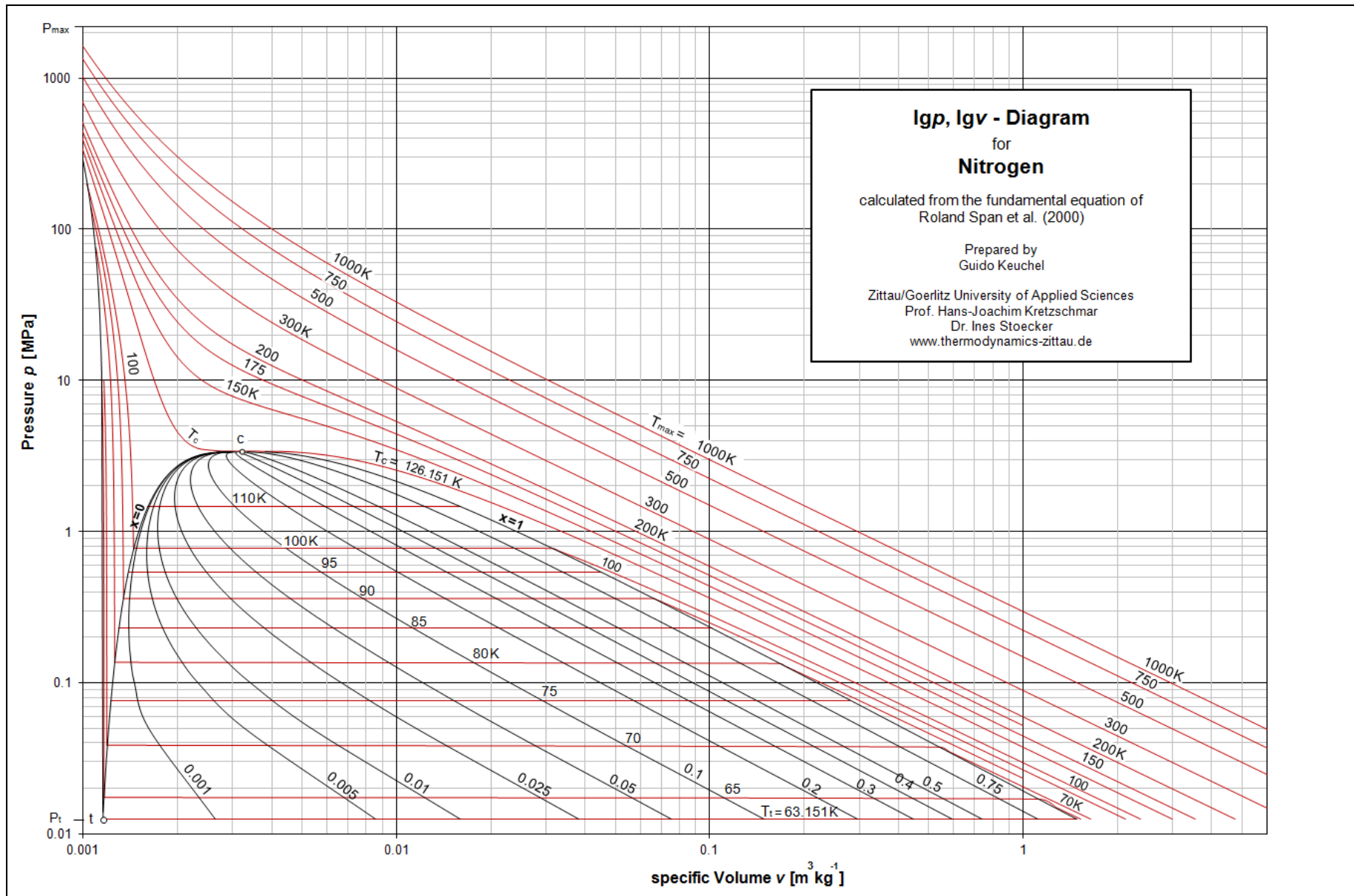
Figure 1.3: *lg p-lg v* diagram

lgp, h - Diagram
for
Nitrogen
calculated from the fundamental equation of
Roland Span et al. (2000)

Prepared by
Guido Keuchel

Zittau/Goerlitz University of Applied Sciences
Prof. Hans-Joachim Kretzschmar
Dr. Ines Stoecker
www.thermodynamics-zittau.de

Figure 1.4: *lg p-h* diagram
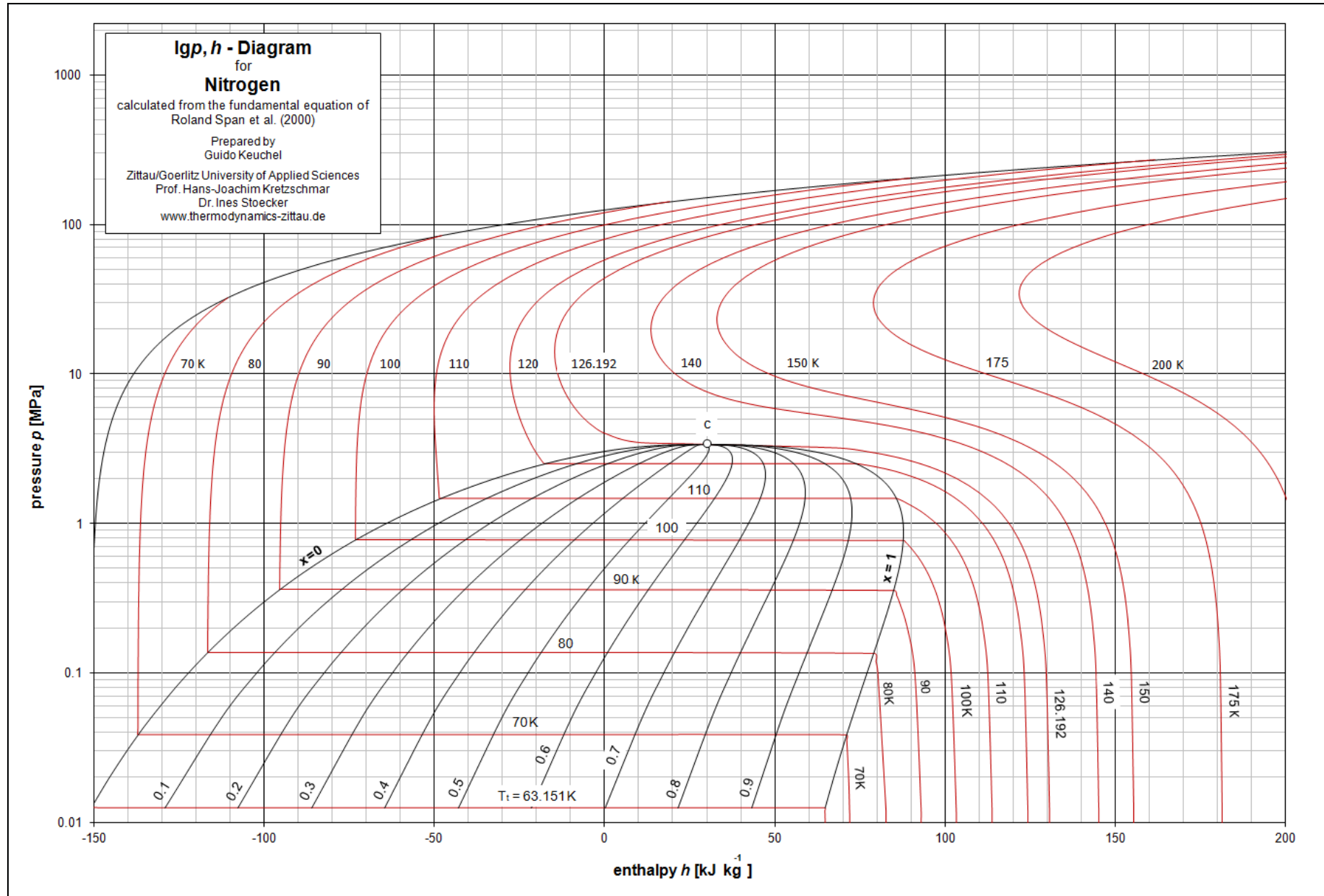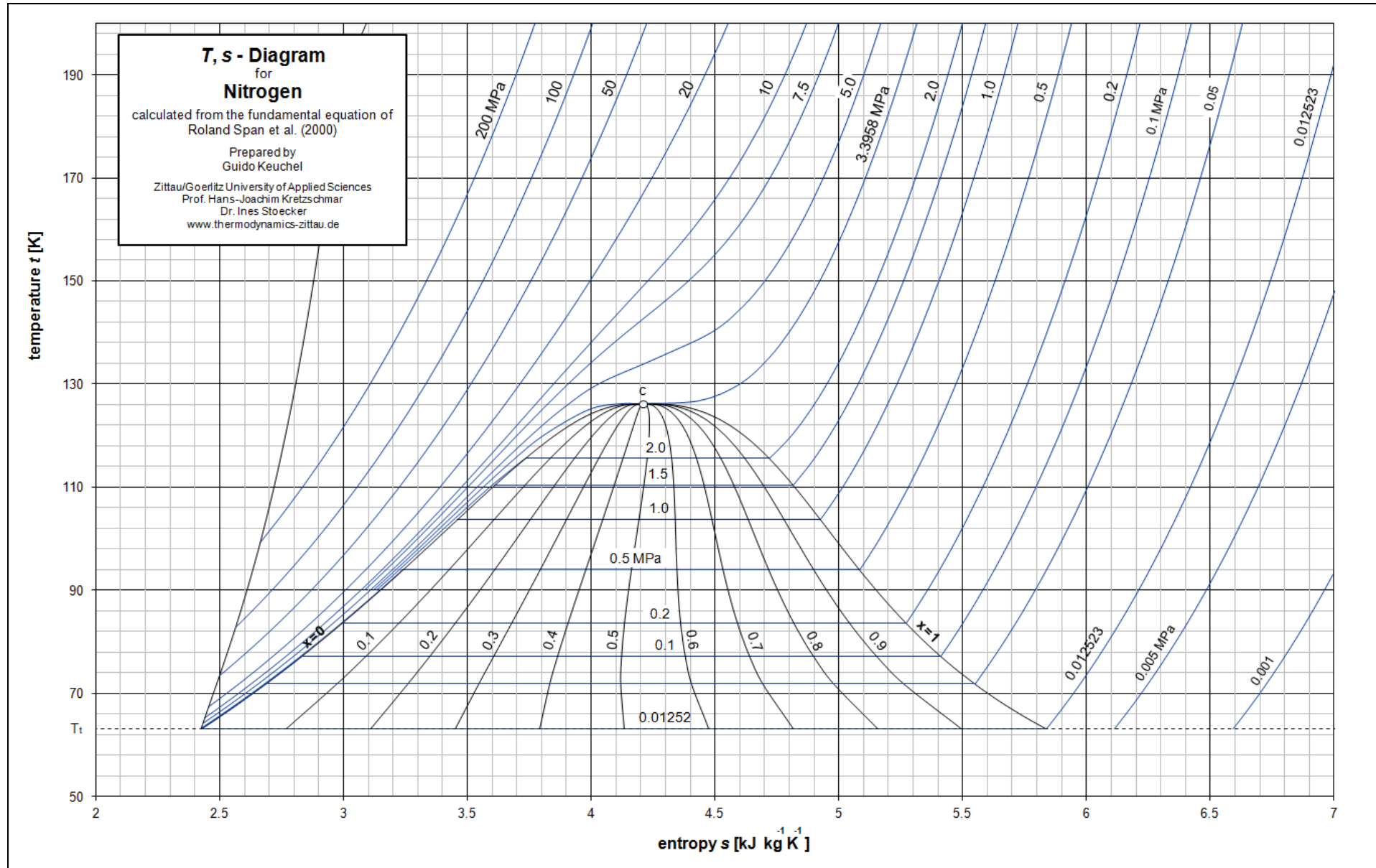
Figure 1.5: *T-s* diagram

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 LibN2 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_LibN2_x64_Eng.zip   (for 64 bit version)

or

   CD_FluidEXL_Graphics_LibN2_Eng.zip"   (for 32 bit version).

you will see the folder

   \CD_FluidEXL_Graphics_LibN2_x64_Eng\   (for 64 bit version)

or

   \CD_FluidEXL_Graphics_LibN2_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_LibN2_Docu_Eng
   LC.dll
   LibN2.dll
   LibN2.chm
   Reg_.reg

Now, please copy the following folders and files

   \FLUFT\
   \Formulation97\
   FluidEXL_Graphics_Eng.xla
   LibN2.dll
   LibN2.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)
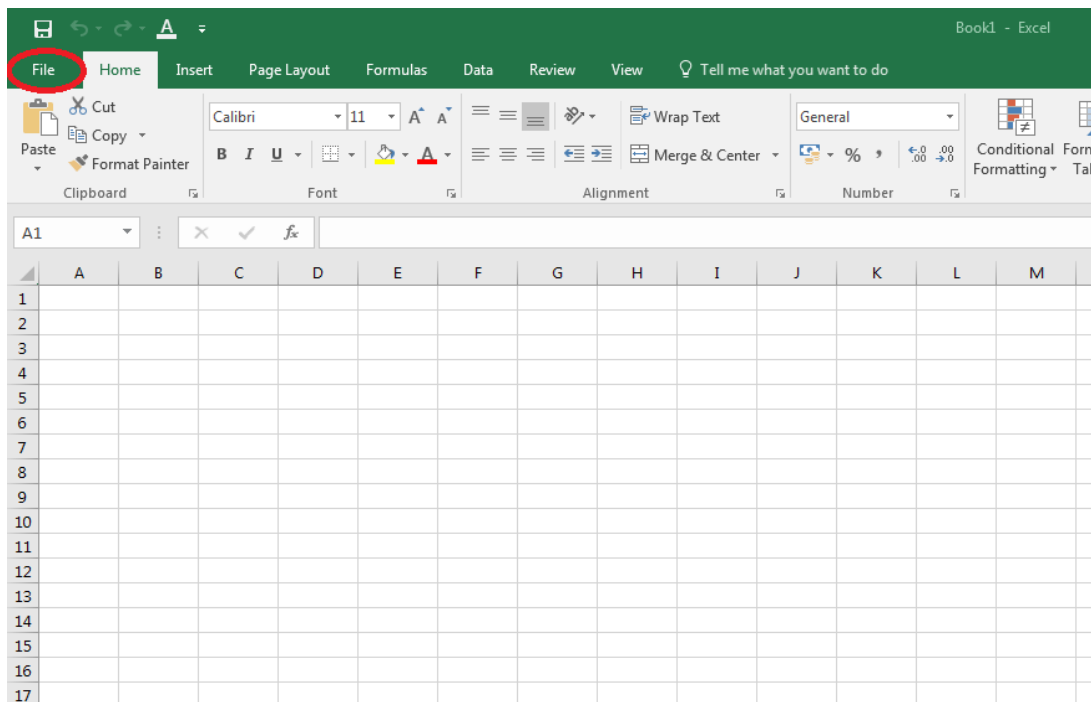
Figure 2.1: Registering FluidEXL*Graphics* as Add-In in Excel® 2016

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

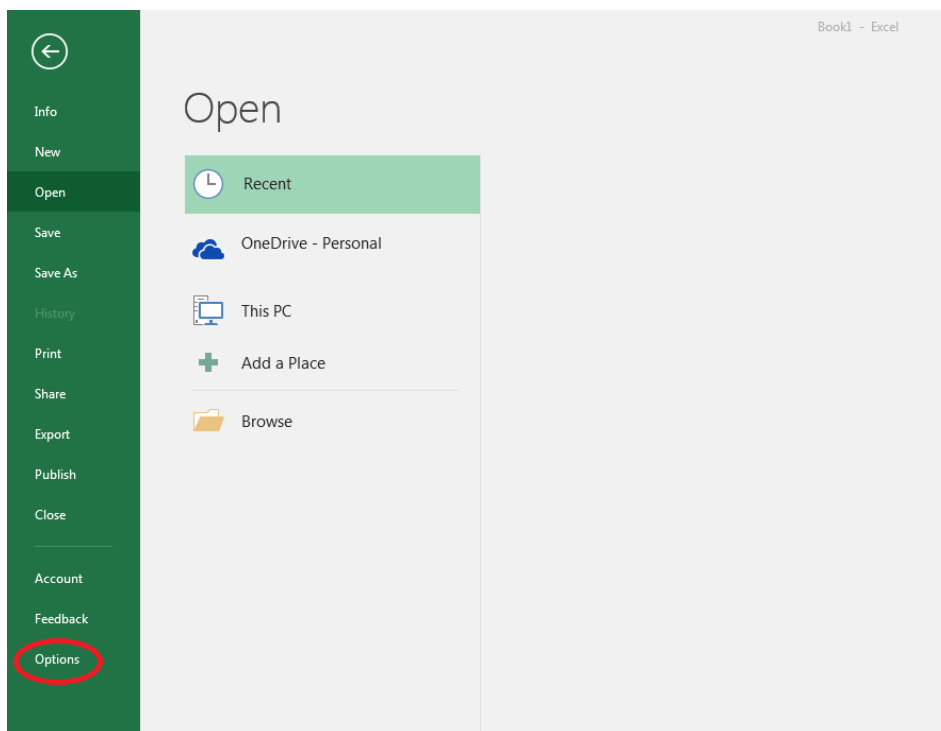**Figure 2.2:** Registering FluidEXL*Graphics* as Add-In in Excel® 2016

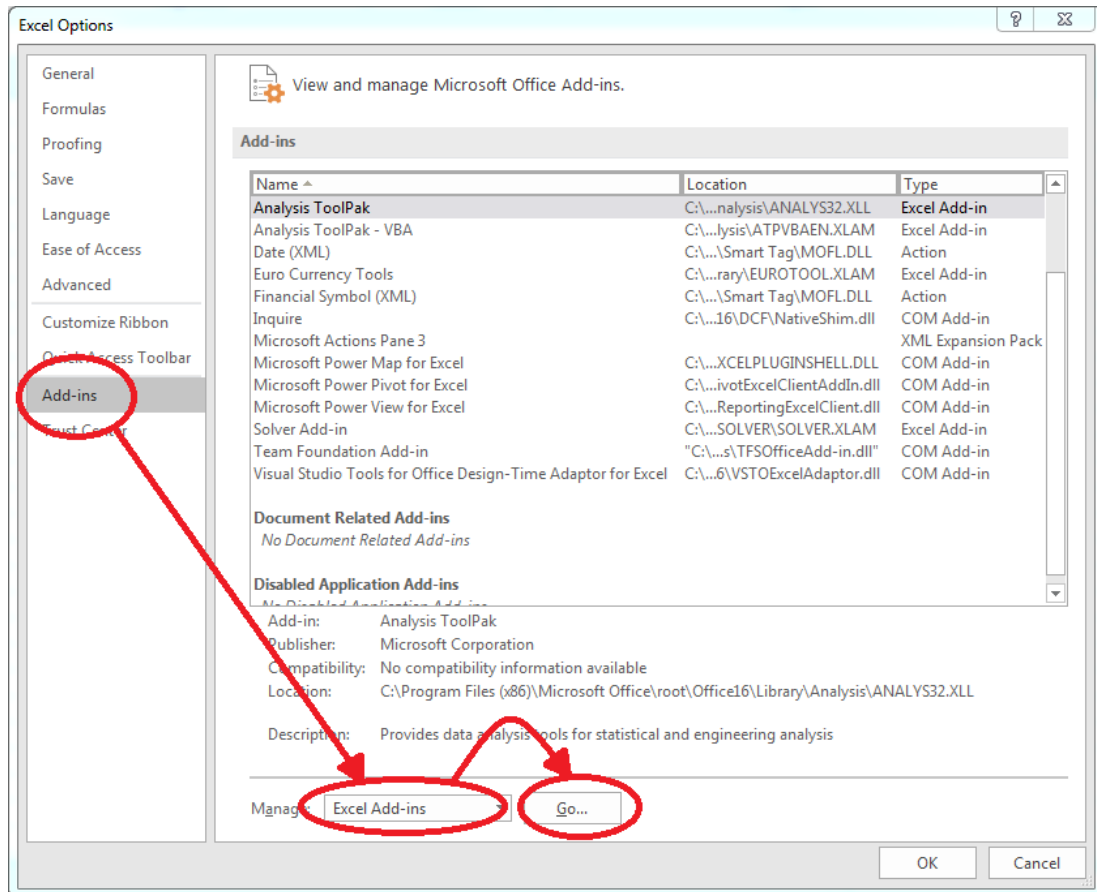- Click on "Add-Ins" in the next menu (Fig. 2.3)

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)
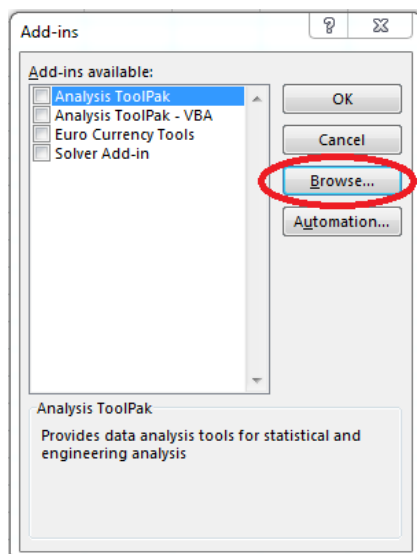
Figure 2.4: Dialog window "Add-ins"

- 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.
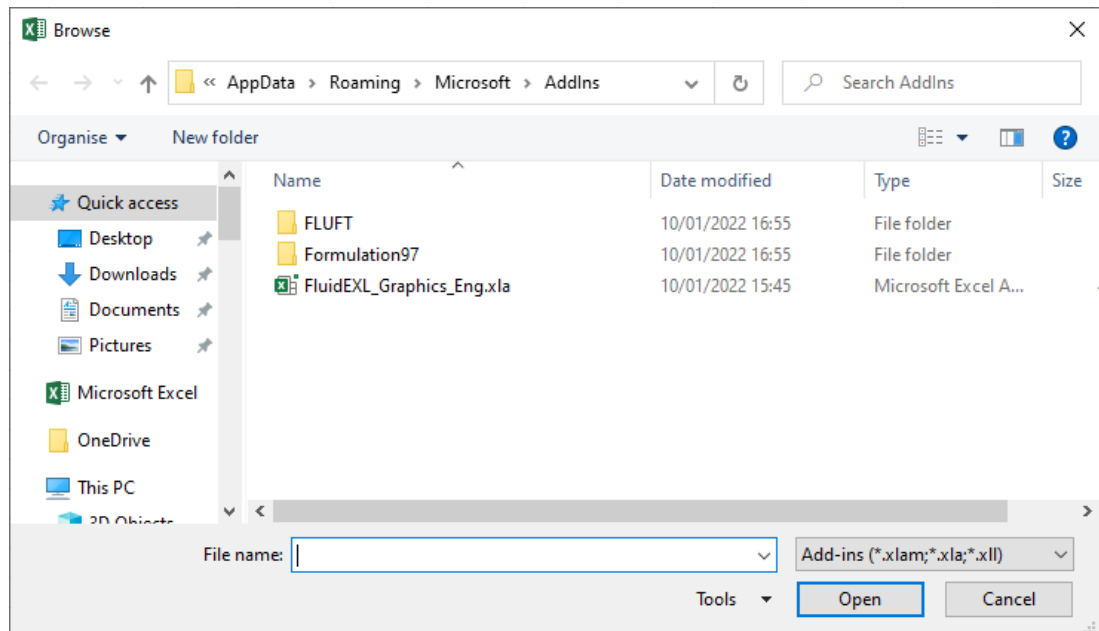
Figure 2.5: "Browse"-Window

  > 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
  >> LibN2.dll
  >> LibN2.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).
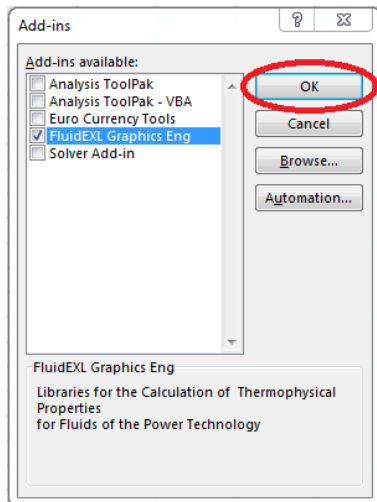
Figure 2.6: Dialog window "Add-Ins"

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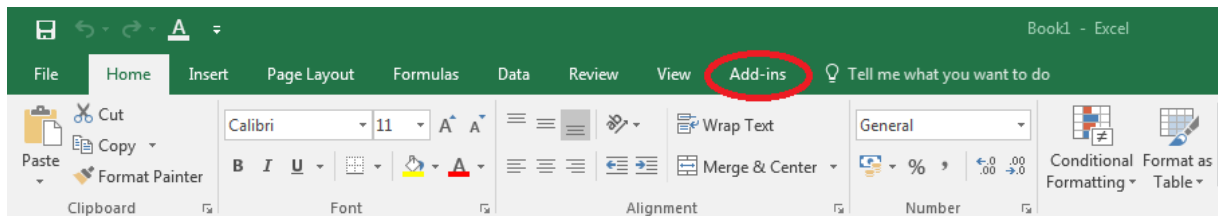
Figure 2.7: Menu item "Add-Ins"

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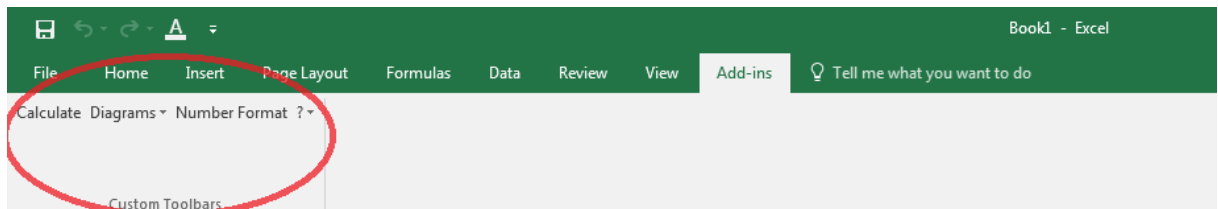
Figure 2.8: FluidEXL^{Graphics} menu bar

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

An example calculation of "LibN2" DLL library property functions can be found in chapter 2.4.

2.3   Licensing the LibN2 Property LibN2rary

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).
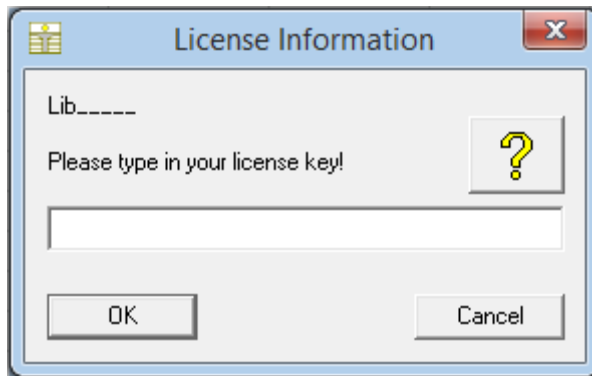
Figure 2.12: "License Information" window

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:
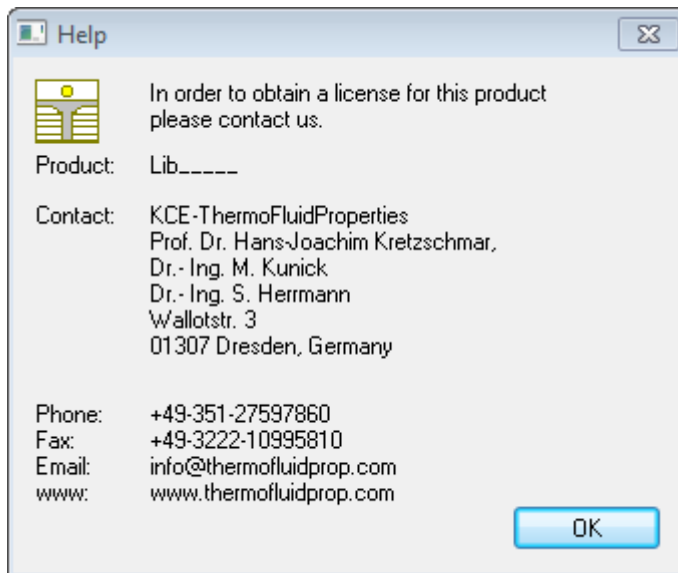
Figure 2.13: "Help" window

If you do not enter a valid license it is still possible to start Excel® by clicking "Cancel" twice. In this case, the LibN2 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 LibN2 property library, you have to delete the files

LibN2.dll
LibN2.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 "LibN2_ _ _ _ _ in Figure 2.12 and 2.13 stands for the LibN2rary you are installing. In this case it is the LibN2 library.

2.4   Example calculation

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

- Start Excel$^®$
- Enter a value for p in bar in a cell
  (Range of validity corresponding to SPAN: p = 0.00001 ... 22000 bar)

  $\Rightarrow$ e. g.: Enter the value 100 into cell A2
- Enter a value for t in °C in a cell
  (Range of validity corresponding to SPAN: t = -207.999 (65.151 K) ... 726.85°C (1000 K))

  $\Rightarrow$ e. g.: Enter the value 400 into cell B2
- Enter a value for x in kg saturated steam/kg wet steam in a cell

  Since the wet steam region is calculated automatically by the subprograms, the following fixed details on the vapor fraction x are to be considered when the value for x is entered:

  Single-phase region

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

  Wet-steam region

    When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for x. It is adequate to enter either the given value for t and p = –1, or the given value for p and t = –1, plus the value for x between 0 and 1. When p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1.

  Wet steam region of LibN2 corresponding to SPAN:
      t_t = -207.999 (65.151 K) ... t_c = -146.958 (126.192 K)
      p_t = 0.00001 bar ... p_c = 33.3958 bar   (c – critical point)

  $\Rightarrow$ e.g.: Enter –1 into the C2 cell.
- Click the cell in which the enthalpy h in kJ/kg is to be displayed.

  $\Rightarrow$ e.g.: Click the D2 cell.
- Click "Calculate" in the menu bar of FluidEXL^{Graphics}.
  Now the "Insert Function" window appears (see next figure).
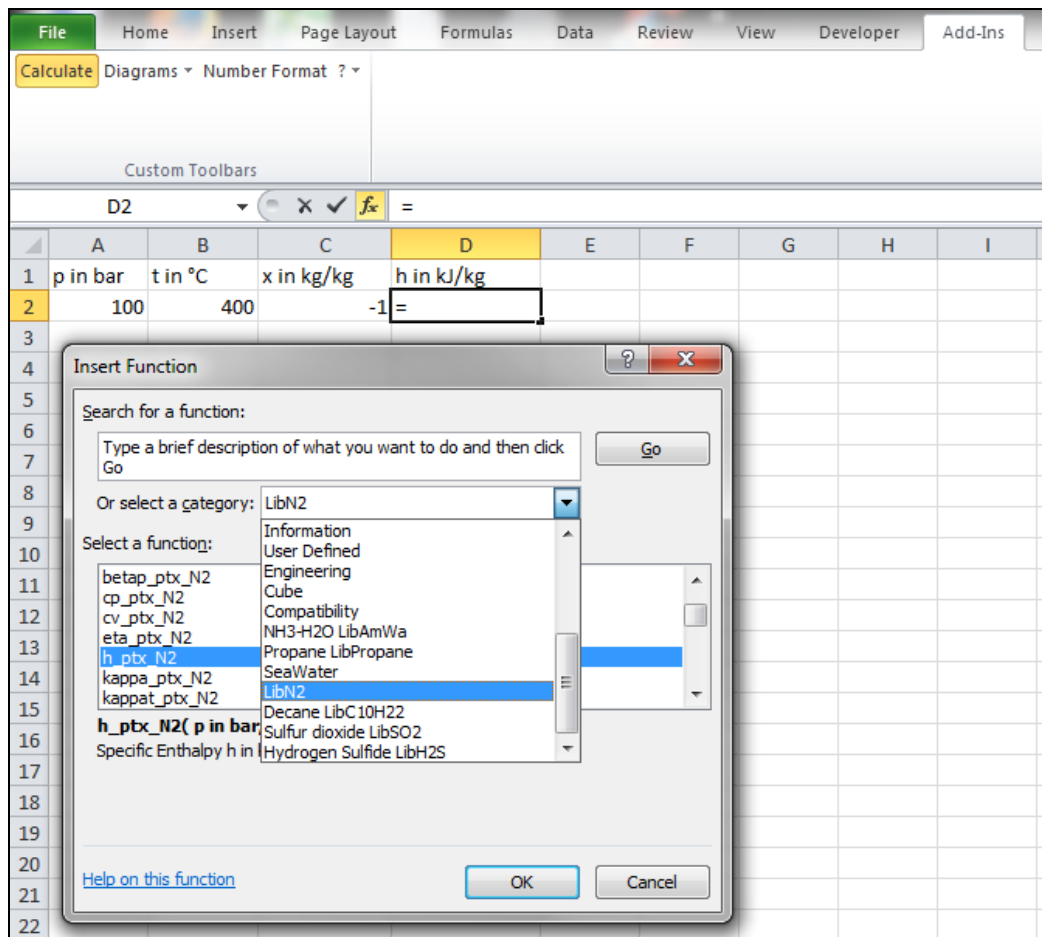
Figure 2.14: Choice of library and function name

- Search and click the "LibN2" library under "Or select a category:" in the upper part of the window.

- Search and click the h_ptx_N2 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 the next figure will now appear.
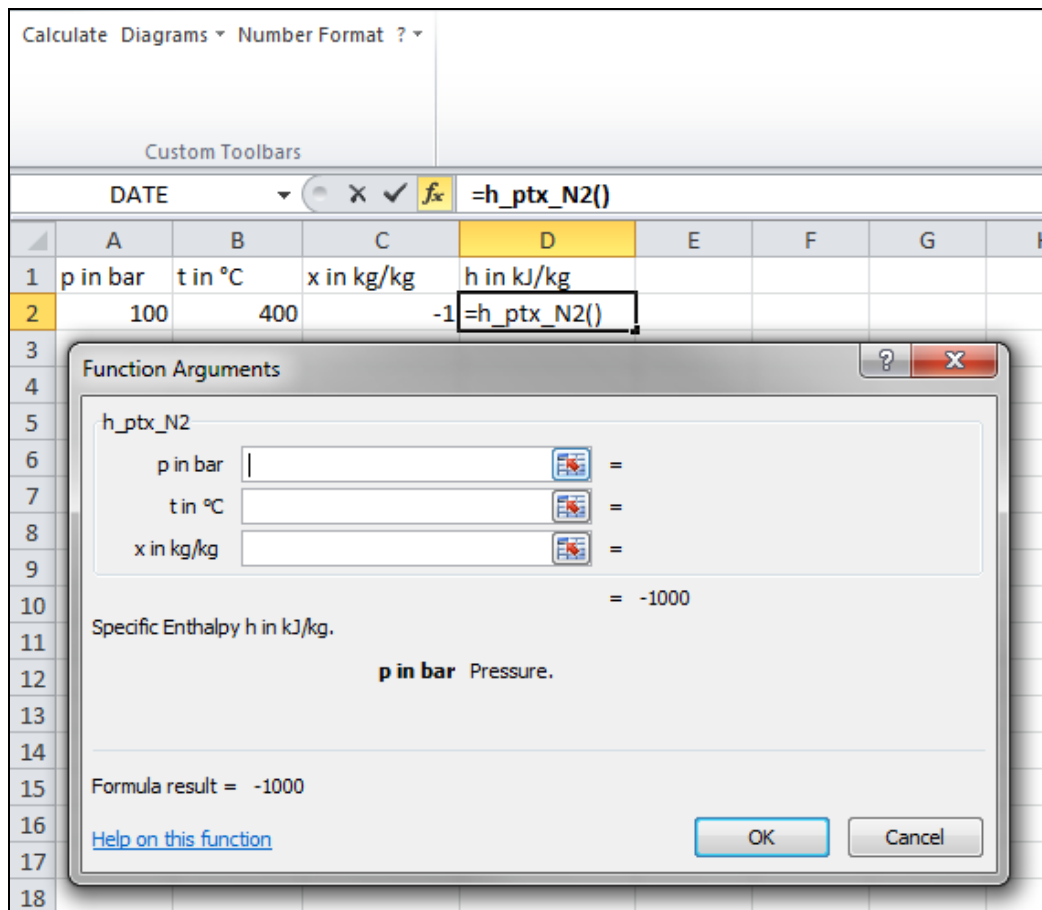
Figure 2.15: Input menu for the function

- The Cursor is now situated on the line next to "p in bar". You can now enter the value for *p* either by clicking the cell with the value for *p*, by entering the name of the cell with the value for *p*, or by entering the value for *p* directly.

  ⇒ e. g.: Click on the cell A2

- 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.: Type B2 into the window next to "t in °C"

- 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.: Click on the cell C2

The window should now look like the following figure:

Calculate Diagrams ▾ Number Format ? ▾

Custom Toolbars

DATE	▾	× ✓	f_x	=h_ptx_N2(A2;B2;C2)

	A	B	C	D	E	F	G	H
1	p in bar	t in °C	x in kg/kg	h in kJ/kg				
2	100	400	-1	;B2;C2)				
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								

Function Arguments

h_ptx_N2

p in bar	A2	= 100
t in °C	B2	= 400
x in kg/kg	C2	= -1

= 708.6899045

Specific Enthalpy h in kJ/kg.

x in kg/kg   Vapor fraction

Formula result =   708.6899045

Help on this function   OK   Cancel
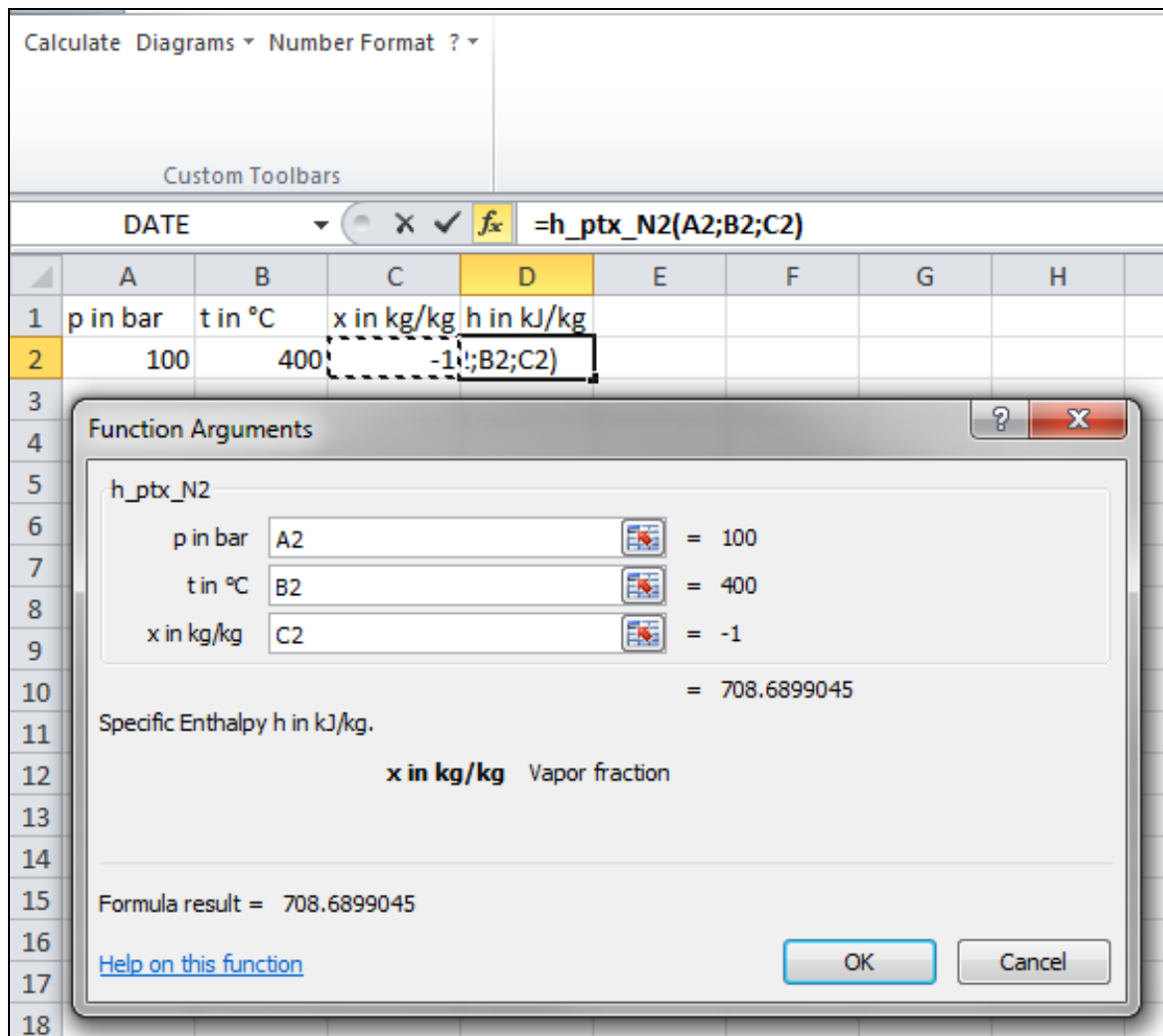
Figure 2.16: Input menu showing the result

- Click the "OK" button.

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

⇒ The result in our sample calculation here is: h = 708.6899045 in kJ/kg.

The calculation of *h* = f(*p*,*t*,*x*) has thus been completed. Correspondingly, the specific entropy *s* = f(*p*,*t*,*x*) can be calculated with the same values for *p*, *t*, and *x*.

- Click the cell in which the entropy *s* in kJ/(kg K) is to be displayed.

   ⇒ e.g.: Click the cell E2.

- Click "Calculate" in the menu bar of FluidEXL^{Graphics}.
 The "Insert Function" window will appear.

- Because of the previous calculation, the "LibN2" library under "Or select a category:" will be marked automatically.

- Search for and click on the s_ptx_N2 function under "Select a function:" in the center of the window.

- Click "OK".
  The "Function Arguments" window appears.

- Enter the cell name with the value of *p* next to "p in bar", or click on the cell with the value of *p*.

- Situate the cursor next to "t in °C", click and enter the cell name with the value of t, or click on the cell with the value of t.

- Situate the cursor next to "x in kg/kg", click and enter the cell name with the value of x, or click on the cell with the value of x.

- Click "OK".

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

$\Rightarrow$ The result in our sample calculation here is: 6.32283301 in kJ/kg K.

The calculation of $s = f(p,t,x)$ has been carried out. You can now arbitrarily change the values for p, T, or x in the appropriate cells. The specific enthalpy and the specific entropy are recalculated and updated every time you change the data. This shows that the Excel® data flow and the DLL calculations are working together successfully.

Note:

If the calculation results in –1, this indicates that the entered values are located outside the range of validity of SPAN. 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 "LibN2" 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.
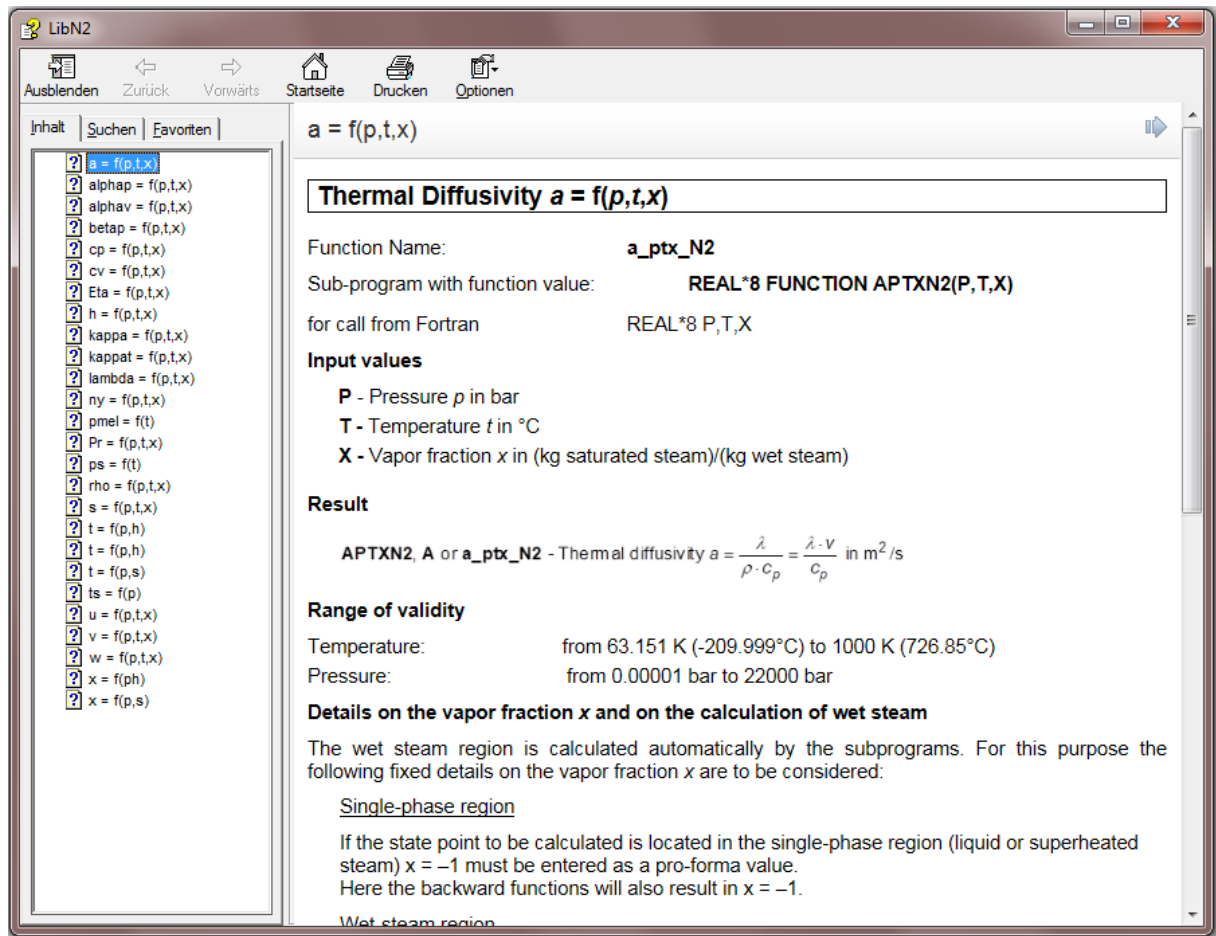
Figure 2.17: Help Window

If the LibN2.chm function help cannot be found, you will be redirected to a Microsoft® help website by your standard browser. In this case, the LibN2.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 LibN2 Library

Should you wish to remove only the LibN2 library, delete the files

LibN2.dll
LibN2.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
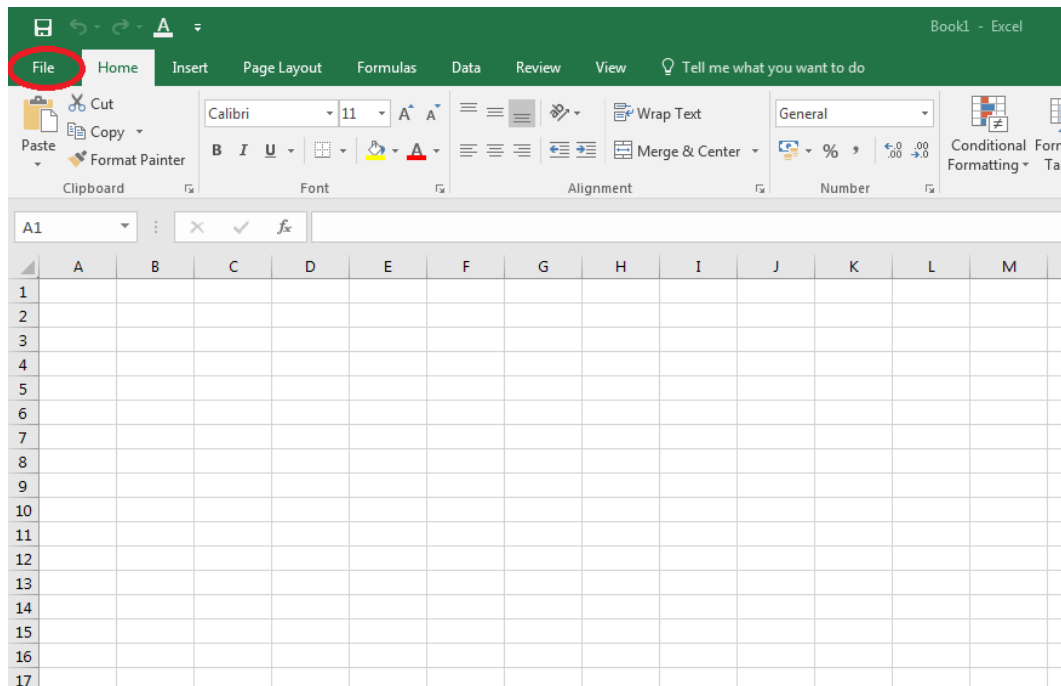
Figure 2.18: Unregistering FluidEXL^{Graphics} as Add-In in Excel® 2016
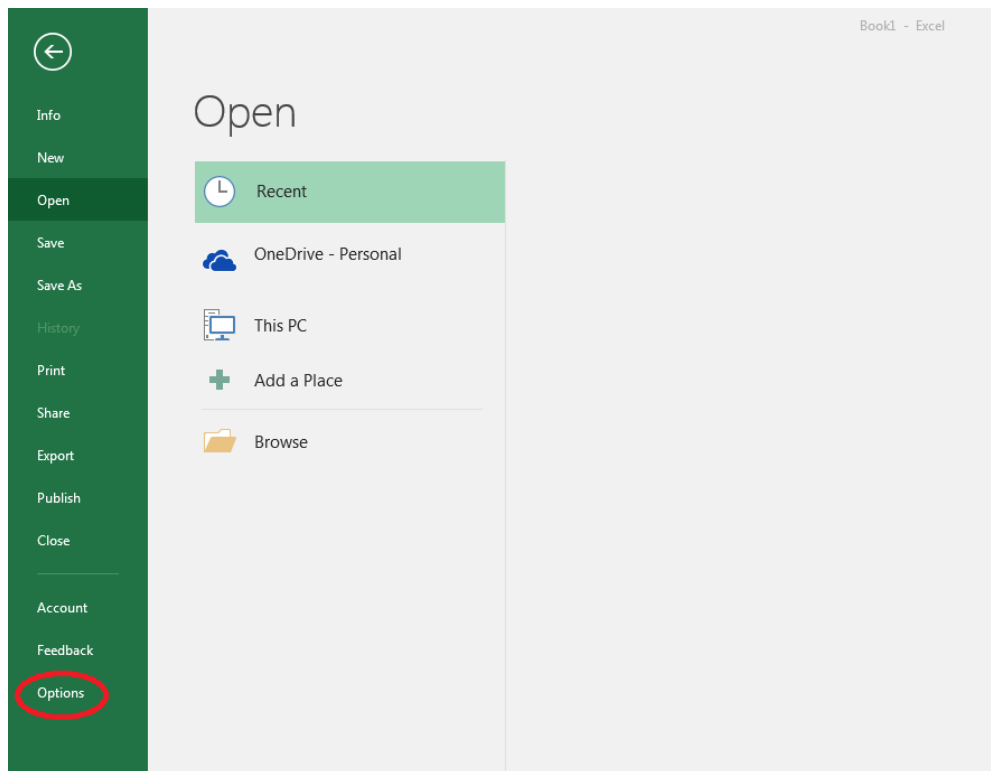
Figure 2.19 Unregistering FluidEXL^{Graphics} as Add-In in Excel® 2016

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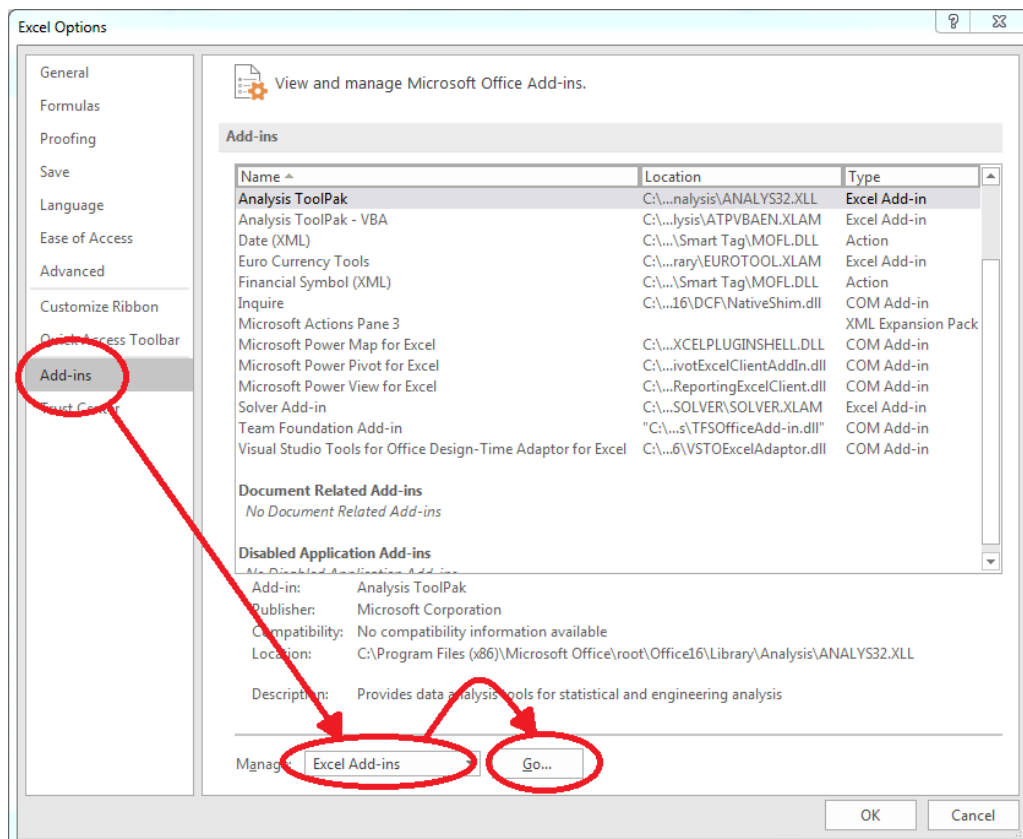
Figure 2.20: Dialog window "Add-Ins"

- 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.
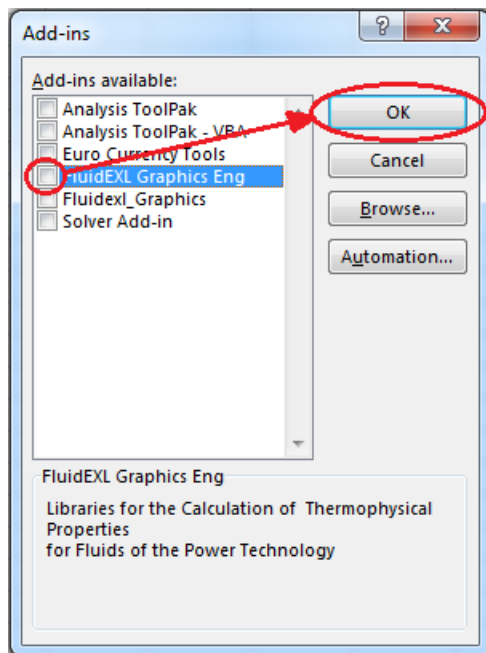
Figure 2.21: Dialog window "Add-Ins"

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} completely, proceed as follows: First the registration of

    FluidEXL_Graphics_Eng.xla

has to be cancelled in Excel®.

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

    "FluidEXL Graphics Eng"

in the window that appears and click the "OK" button. The additional menu bar of FluidEXL^{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

LibN2.dll
LibN2.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 $a = \mathrm{f}(p,t,x)$

Function Name: **a_ptx_N2**

Sub-program with function value: **REAL*8 FUNCTION APTXN2(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 - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

   APTXN2, **A** or **a_ptx_N2** - Thermal diffusivity $a = \dfrac{\lambda}{\rho \cdot c_p} = \dfrac{\lambda \cdot v}{c_p}$ in m^2/s

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the vapor fraction x and on the calculation of wet steam

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

   Single-phase region

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

   Wet-steam region

   When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for *x*. It is adequate to enter either the given value for t and p = –1000, or the given value for p and t = –1000, plus the value for *x* between 0 and 1. When *p* and *t* and *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

   (Wet steam region of LibN2: t_t = -209.999 °C   ... p_t = 0.12523 bar   (t – triple point)
                                        t_c = -146.958 °C   ... p_c = 33.958 bar   (c – critical point)

Results for wrong input values

Result **APTXN2, A = –1** or **a_ptx_N2 = –1000** for input values:

Single phase region: p > 22000 bar or p < 0.00001 bar or
(x = –1) t > 726.85°C or t < -146.958 °C or $t < t_{mel}(p)$

Saturation lines: at p = –1000 and t > -146.958 °C   or t < -209.999 °C
(x = 0 or x = 1)   at t = –1000 and p > 33.958 bar or p < 0.00001 bar or
                         at p < 33.958 bar or p > 0.00001 bar
                            and $|t-t_s(p)| > 0.1$ K

References: [1], [2]

Relative Pressure Coefficient α_p = f(p,t,x)

Function Name: **ALPHAP_ptx_N2**

Sub-program with function value: **REAL*8 FUNCTION ALPHAPPTXN2(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 - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

    ALPHAPPTXN2, **ALPHAP** or **alphap_ptx_N2** - Relative pressure coefficient α_p in 1/K

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the vapor fraction x and on the calculation of wet steam

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

Single-phase region

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

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for x. It is adequate to enter either the given value for t and p = –1000, or the given value for p and t = –1000, plus the value for x between 0 and 1. When p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Wet steam region of LibN2: t_t = -209.999 °C   ... p_t = 0.12523 bar   (t – triple point)

                                      t_c = -146.958 °C   ... p_c = 33.958 bar   (c – critical point)

Results for wrong input values

Result **ALPHAPPTXN2, ALPHAP = –1000** or **alphap_ptx_N2 = –1000** for input values:

Single phase region: p > 22000 bar or p < 0.00001 bar or
(x = –1) t > 726.85°C or t < -146.958 °C or t < $t_{mel}(p)$

Saturation lines: at p = –1000 and t > -146.958 °C   or t < -209.999 °C
(x = 0 or x = 1)   at t = –1000 and p > 33.958 bar or p < 0.00001 bar or
                      at p < 33.958 bar or p > 0.00001 bar
                        and $|t-t_s(p)|$ > 0.1 K

References: [1], [2]

Isobaric Cubic Expansion Coefficient $\alpha_v = f(p,t,x)$

Function Name: **ALPHAV_ptx_N2**

Sub-program with function value: **REAL*8 FUNCTION ALPHAVPTXN2(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 - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

   ALPHAVPTXN2, **ALPHAV** or **alphav_ptx_N2** - Isobaric cubic expansion coefficient α_v in 1/K

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the vapor fraction *x* and on the calculation of wet steam

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

Single-phase region

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

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for *x*. It is adequate to enter either the given value for t and p = –1000, or the given value for p and t = –1000, plus the value for *x* between 0 and 1. When *p* and *t* and *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Wet steam region of LibN2: t_t = -209.999 °C   ... p_t = 0.12523 bar   (t – triple point)

                                      t_c = -146.958 °C   ... p_c = 33.958 bar   (c – critical point)

Results for wrong input values

Result **ALPHAVPTXN2, ALPHAV = –1000** or **alphav_ptx_N2 = –1000** for input values:

Single phase region: $p > 22000$ bar or $p < 0.00001$ bar or
($x = -1$) $t > 726.85$°C or $t < $ -146.958 °C or $t < t_{mel}(p)$

Saturation lines: at p = –1000 and t > -146.958 °C   or $t < $ -209.999 °C
($x = 0$ or $x = 1$)   at t = –1000 and p > 33.958 bar or $p < 0.00001$ bar or
                          at $p < 33.958$ bar or $p > 0.00001$ bar
                            and $|t\text{-}t_s(p)| > 0.1$ K

References: [1], [2]

Isothermal Stress Coefficient $\beta_p = f(p,t,x)$

Function Name: **BETAP_ptx_N2**

Sub-program with function value: **REAL*8 FUNCTION BETAPPTXN2(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 - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

   BETAPPTXN2, **BETAP** or **betap_ptx_N2** - Isothermal stress coefficient β_p in kg/m^3

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the vapor fraction x and on the calculation of wet steam

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

Single-phase region

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

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for x. It is adequate to enter either the given value for t and p = –1000, or the given value for p and t = –1000, plus the value for x between 0 and 1. When p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Wet steam region of LibN2: t_t = -209.999 °C   ... p_t = 0.12523 bar   (t – triple point)

                     t_c = -146.958 °C   ... p_c = 33.958 bar   (c – critical point)

Results for wrong input values

Result **BETAPPTXN2, BETAP = –1000** or **betap_ptx_N2 = –1000** for input values:

Single phase region: $p > 22000$ bar or $p < 0.00001$ bar or
(x = –1) $t > 726.85$°C or $t < -146.958$ °C or $t < t_{mel}(p)$

Saturation lines: at p = –1000 and t > -146.958 °C   or $t < -209.999$ °C
(x = 0 or x = 1)   at t = –1000 and p > 33.958 bar or $p < 0.00001$ bar or
              at $p < 33.958$ bar or $p > 0.00001$ bar
                and $|t-t_s(p)| > 0.1$ K

References: [1], [2]

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

Function Name: **cp_ptx_N2**

Sub-program with function value: **REAL*8 FUNCTION CPPTXN2(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 - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

CPPTXN2, **CP** or **cp_ptx_N2** - Specific isobaric heat capacity c_p in kJ/kg K

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the vapor fraction *x* and on the calculation of wet steam

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

Single-phase region

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

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for *x*. It is adequate to enter either the given value for t and p = –1000, or the given value for p and t = –1000, plus the value for *x* between 0 and 1. When *p* and *t* and *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Wet steam region of LibN2: t_t = -209.999 °C ... p_t = 0.12523 bar (t – triple point)

t_c = -146.958 °C ... p_c = 33.958 bar (c – critical point)

Results for wrong input values

Result **CPPTXN2, CP = –1000** or **cp_ptx_N2 = –1000** for input values:

Single phase region: $p > 22000$ bar or $p < 0.00001$ bar or
(*x* = –1) $t > 726.85°C$ or $t < -146.958$ °C or $t < t_{mel}(p)$

Saturation lines: at p = –1000 and t > -146.958 °C or $t < -209.999$ °C
(*x* = 0 or *x* = 1) at t = –1000 and p > 33.958 bar or $p < 0.00001$ bar or
at $p < 33.958$ bar or $p > 0.00001$ bar
and $|t-t_s(p)| > 0.1$ K

References: [2]

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

Function Name: **cv_ptx_N2**

Sub-program with function value: **REAL*8 FUNCTION CVPTXN2 (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 - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

CVPTXN2, **CV** or **cv_ptx_N2** - Specific isochoric heat capacity c_v in kJ/kg K

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the vapor fraction *x* and on the calculation of wet steam

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

Single-phase region

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

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for *x*. It is adequate to enter either the given value for t and p = –1000, or the given value for p and t = –1000, plus the value for *x* between 0 and 1. When *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Wet steam region of LibN2: t_t = -209.999 °C ... p_t = 0.12523 bar (t – triple point)

t_c = -146.958 °C ... p_c = 33.958 bar (c – critical point)

Results for wrong input values

Result **CVPTXN2, CV = –1000** or **cv_ptx_N2 = –1000** for input values:

Single phase region: p > 22000 bar or p < 0.00001 bar or
(x = –1) t > 726.85°C or t < -146.958 °C or $t < t_{mel}(p)$

Saturation lines: at p = –1000 and t > -146.958 °C or t < -209.999 °C
(x = 0 or x = 1) at t = –1000 and p > 33.958 bar or p < 0.00001 bar or
at p < 33.958 bar or p > 0.00001 bar
and $|t - t_s(p)|$ > 0.1 K

References: [2]

Dynamic Viscosity η = f(p,t,x)

Function Name: **Eta_ptx_N2**

Sub-program with function value: **REAL*8 FUNCTION ETAPTXN2(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 - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

   ETAPTXN2, **ETA** or **eta_ptx_N2** - Dynamic viscosity η in Pa s

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the vapor fraction x and on the calculation of wet steam

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

   Single-phase region

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

   Wet-steam region

   When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for x. It is adequate to enter either the given value for t and p = –1000, or the given value for p and t = –1000, plus the value for x between 0 and 1. When p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

   (Wet steam region of LibN2: t_t = -209.999 °C   ... p_t = 0.12523 bar   (t – triple point)

                     t_c = -146.958 °C   ... p_c = 33.958 bar   (c – critical point)

Results for wrong input values

Result **ETAPTXN2, ETA = –1000** or **eta_ptx_N2 = –1000** for input values:

Single phase region: p > 22000 bar or p < 0.00001 bar or
(x = –1) t > 726.85°C or t < -146.958 °C or $t < t_{mel}(p)$

Saturation lines: at p = –1000 and t > -146.958 °C   or t < -209.999 °C
(x = 0 or x = 1)   at t = –1000 and p > 33.958 bar or p < 0.00001 bar or
                  at p < 33.958 bar or p > 0.00001 bar
                    and $|t\text{-}t_s(p)|$ > 0.1 K

References: [2]

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

Function Name:	**h_ptx_N2**
Sub-program with function value:	**REAL*8 FUNCTION HPTXN2(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 - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

HPTXN2, H or **h_ptx_N2** - Specific enthalpy h in kJ/kg

Range of validity

Temperature:	from 63.151 K (-209.999°C) to 1000 K (726.85°C)
Pressure:	from 0.00001 bar to 22000 bar

Details on the vapor fraction x and on the calculation of wet steam

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

Single-phase region

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

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for x. It is adequate to enter either the given value for t and p = −1000, or the given value for p and t = −1000, plus the value for x between 0 and 1. When p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in −1000.

(Wet steam region of LibN2: t_t = -209.999 °C   ... p_t = 0.12523 bar   (t – triple point)

                                  t_C = -146.958 °C   ... p_C = 33.958   bar   (c – critical point)

Results for wrong input values

Result **HPTXN2, H = –1000** or **h_ptx_N2 = –1000** for input values:

Single phase region: $p > 22000$ bar or $p < 0.00001$ bar or
($x = -1$) $t > 726.85$°C or $t < -146.958$ °C or $t < t_{mel}(p)$

Saturation lines: at p = −1000 and t > -146.958 °C   or $t < -209.999$ °C
($x = 0$ or $x = 1$)   at t = −1000 and p > 33.958 bar or $p < 0.00001$ bar or
                      at $p < 33.958$ bar or $p > 0.00001$ bar
                      and $|t-t_s(p)| > 0.1$ K

References: [2]

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

Function Name:	**Kappa_ptx_N2**
Sub-program with function value:	**REAL*8 FUNCTION KAPPAPTXN2(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 -** Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

KAPPAPTXN2, **KAPPA** or **kappa_ptx_N2** - Isentropic exponent $\kappa = -\dfrac{v}{p}\left(\dfrac{\partial p}{\partial v}\right)_s = \dfrac{w^2}{p \cdot v}$

Range of validity

Temperature:	from 63.151 K (-209.999°C) to 1000 K (726.85°C)
Pressure:	from 0.00001 bar to 22000 bar

Details on the vapor fraction x and on the calculation of wet steam

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

Single-phase region

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

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for x. It is adequate to enter either the given value for t and p = –1000, or the given value for p and t = –1000, plus the value for x between 0 and 1. When p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Wet steam region of LibN2: t_t = -209.999 °C   ... p_t = 0.12523 bar   (t – triple point)

                                          t_C = -146.958 °C   ... p_C = 33.958   bar   (c – critical point)

Results for wrong input values

Result **KAPPAPTXN2, KAPPA = –1000** or **kappa_ptx_N2 = –1000** for input values:

Single phase region:	$p > 22000$ bar or $p < 0.00001$ bar or
($x = -1$)	$t > 726.85$°C or $t < $ -146.958 °C or $t < t_{mel}(p)$

Saturation lines:	at p = –1000 and t > -146.958 °C or $t < $ -209.999 °C
($x = 0$ or $x = 1$)	at t = –1000 and p > 33.958 bar or $p < 0.00001$ bar or
	at $p < 33.958$ bar or $p > 0.00001$ bar
	and $\lvert t - t_s(p)\rvert > 0.1$ K

References: [1], [2]

Isothermal Compressibility κ_T = f(p,t,x)

Function Name:	**kappat_ptx_N2**
Sub-program with function value: for call from Fortran	**REAL*8 FUNCTION KAPPATPTXN2(P,T,X)** REAL*8 P,T,X

Input values

  P - Pressure p in bar

  T - Temperature t in °C

  X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

  KAPPATPTXN2, **KAPPAT** or **kappat_ptx_N2** - Isothermal compressibility κ_T in 1/ kPa

Range of validity

Temperature:	from 63.151 K (-209.999°C) to 1000 K (726.85°C)
Pressure:	from 0.00001 bar to 22000 bar

Details on the vapor fraction *x* and on the calculation of wet steam

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

<u>Single-phase region</u>

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

<u>Wet-steam region</u>

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for *x*. It is adequate to enter either the given value for t and p = –1000, or the given value for p and t = –1000, plus the value for *x* between 0 and 1. When *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Wet steam region of LibN2: $\quad t_t$ = -209.999 °C ... p_t = 0.12523 bar (t – triple point)

$\qquad\qquad\qquad\qquad\qquad\qquad t_c$ = -146.958 °C ... p_c = 33.958 bar (c – critical point)

Results for wrong input values

Result **KAPPATPTXN2, KAPPAT = –1000** or **kappat_ptx_N2 = –1000** for input values:

Single phase region: (x = –1)	p > 22000 bar or p < 0.00001 bar or t > 726.85°C or t < -146.958 °C or t < $t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)	at p = –1000 and t > -146.958 °C or t < -209.999 °C at t = –1000 and p > 33.958 bar or p < 0.00001 bar or at p < 33.958 bar or p > 0.00001 bar and $\lvert t\text{-}t_s(p)\rvert$ > 0.1 K

References: [1], [2]

Thermal Conductivity λ = f(p,t,x)

Function Name: **Lambda_ptx_N2**

Sub-program with function value: **REAL*8 FUNCTION LAMPTXN2(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 - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

  LAMPTXN2, **LAMBDA** or **lambda_ptx_N2** - Thermal conductivity λ in W/m·K

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the vapor fraction *x* and on the calculation of wet steam

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

Single-phase region

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

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for *x*. It is adequate to enter either the given value for t and p = –1000, or the given value for p and t = –1000, plus the value for *x* between 0 and 1. When *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Wet steam region of LibN2: t_t = -209.999 °C   ... p_t = 0.12523 bar   (t – triple point)

t_c = -146.958 °C   ... p_c = 33.958 bar   (c – critical point)

Results for wrong input values

Result **LAMPTXN2, LAMBDA = –1000** or **Lambda_ptx_N2 = –1000** for input values:

Single phase region: $p > 22000$ bar or $p < 0.00001$ bar or
(*x* = –1) $t > 726.85°C$ or $t < $ -146.958 °C or $t < t_{mel}(p)$

Saturation lines: at p = –1000 and t > -146.958 °C   or $t < $ -209.999 °C
(*x* = 0 or *x* = 1)   at t = –1000 and p > 33.958 bar or $p < 0.00001$ bar or
  at $p < 33.958$ bar or $p > 0.00001$ bar
    and $|t\text{-}t_s(p)| > 0.1$ K

References: [1], [2]

Kinematic Viscosity ν = f(p,t,x)

Function Name: **Ny_ptx_N2**

Sub-program with function value: **REAL*8 FUNCTION NYPTXN2(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 -** Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

> **NYPTXN2**, **NY** or **ny_ptx_N2** - Kinematic viscosity $\nu = \dfrac{\eta}{\rho} = \eta \cdot v$ in m^2 / s

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)
Pressure: from 0.00001 bar to 22000 bar

Details on the vapor fraction x and on the calculation of wet steam

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

Single-phase region

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

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for x. It is adequate to enter either the given value for t and p = –1000, or the given value for p and t = –1000, plus the value for x between 0 and 1. When p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Wet steam region of LibN2: t_t = -209.999 °C   ... p_t = 0.12523 bar   (t – triple point)

t_c = -146.958 °C   ... p_c = 33.958 bar   (c – critical point)

Results for wrong input values

Result **NYPTXN2, NY = –1000** or **Ny_ptx_N2 = –1000** for input values:

Single phase region: p > 22000 bar or p < 0.00001 bar or
(x = –1) t > 726.85°C or t < -146.958 °C or $t < t_{mel}(p)$

Saturation lines: at p = –1000 and t > -146.958 °C   or t < -209.999 °C
(x = 0 or x = 1)   at t = –1000 and p > 33.958 bar or p < 0.00001 bar or
                         at p < 33.958 bar or p > 0.00001 bar
                            and $|t$-$t_s(p)|$ > 0.1 K

References: [1], [2]

Melting Pressure p_{mel} = f(t)

Function Name: **pmel_t_N2**

Sub-program with function value: **REAL*8 FUNCTION PMELTN2(T)**
for call from Fortran   REAL*8 PMELT,T

Input values

   T - temperature t in °C

Result

PMELTN2, **P** or **pmel_t_N2** – Melting pressure p_{mel} in bar

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Results for wrong input values

Result **PMELTN2, P = –1000** or **pmel_t_N2 = –1000** for input values:
   $p < 0.00001$ bar or $p > 22000$ bar

References: [1], [2]

Prandtl Number *Pr* = f(*p,t,x*)

Function Name: **Pr_ptx_N2**

Sub-program with function value: **REAL*8 FUNCTION PRPTXN2(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** - Vapor fraction *x* in (kg saturated steam)/(kg wet steam)

Result

PRPTXN2, **Pr** or **Pr_ptx_N2** - Prandtl number $Pr = \dfrac{v}{a} = \dfrac{\eta \cdot c_p}{\lambda}$

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the vapor fraction *x* and on the calculation of wet steam

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

Single-phase region

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

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for *x*. It is adequate to enter either the given value for t and p = –1000, or the given value for p and t = –1000, plus the value for *x* between 0 and 1. When *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Wet steam region of LibN2: t_t = -209.999 °C   ... p_t = 0.12523 bar   (t – triple point)

t_c = -146.958 °C   ... p_c = 33.958 bar   (c – critical point)

Results for wrong input values

Result **PRPTXN2, PR = –1000** or **Pr_ptx_N2 = –1000** for input values:

Single phase region: *p* > 22000 bar or *p* < 0.00001 bar or
(*x* = –1)   *t* > 726.85°C or *t* < -146.958 °C or $t < t_{mel}(p)$

Saturation lines: at p = –1000 and t > -146.958 °C   or *t* < -209.999 °C
(*x* = 0 or *x* = 1)   at t = –1000 and p > 33.958 bar or *p* < 0.00001 bar or
                        at *p* < 33.958 bar or *p* > 0.00001 bar
                          and $|t\text{-}t_s(p)| > 0.1$ K

References: [1], [2]

Vapor Pressure p_s = f(t)

Function Name: **ps_t_N2**

Sub-program with function value: **REAL*8 FUNCTION PSTN2(T)**
for call from Fortran   REAL*8 T

Input values

   T - Temperature t in °C

Result

PSTN2, **PS** or **ps_t_N2** – Vapor pressure p_s in bar

Range of validity

from t_t = -209.999 °C   to t_c = -146.958 °C

Results for wrong input values

Result **PSTN2, PS = –1000** or **ps_t_N2 = –1000** for input values:
   t < -209.999 °C   or t > -146.958 °C

References: [2]

Density ρ = f(p,t,x)

Function Name: **Rho_ptx_N2**

Sub-program with function value: **REAL*8 FUNCTION RHOPTXN2(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 - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

    RHOPTXN2, **RHO** or **rho_ptx_N2** - Density $\rho = \dfrac{1}{v}$ in kg / m^3

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the vapor fraction *x* and on the calculation of wet steam

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

Single-phase region

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

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for *x*. It is adequate to enter either the given value for t and p = –1000, or the given value for p and t = –1000, plus the value for *x* between 0 and 1. When *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Wet steam region of LibN2: t_t = -209.999 °C   ... p_t = 0.12523 bar   (t – triple point)

                                     t_c = -146.958 °C   ... p_c = 33.958 bar   (c – critical point)

Results for wrong input values

Result **RHOPTXN2, RHO = –1000** or **rho_ptx_N2 = –1000** for input values:

Single phase region: p > 22000 bar or p < 0.00001 bar or
(x = –1) t > 726.85°C or t < -146.958 °C or t < $t_{mel}(p)$

Saturation lines: at p = –1000 and t > -146.958 °C   or t < -209.999 °C
(x = 0 or x = 1)   at t = –1000 and p > 33.958 bar or p < 0.00001 bar or
                       at p < 33.958 bar or p > 0.00001 bar
                         and |t-$t_s(p)$| > 0.1 K

References: [2]

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

Function Name: **s_ptx_N2**

Sub-program with function value: **REAL*8 FUNCTION SPTXN2(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 - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

SPTXN2, S or **s_ptx_N2** - Specific entropy s in kJ/kg K

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the vapor fraction x and on the calculation of wet steam

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

Single-phase region

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

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for x. It is adequate to enter either the given value for t and p = –1000, or the given value for p and t = –1000, plus the value for x between 0 and 1. When p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Wet steam region of LibN2: t_t = -209.999 °C   ... p_t = 0.12523 bar   (t – triple point)

                                      t_C = -146.958 °C   ... p_C = 33.958   bar   (c – critical point)

Results for wrong input values

Result **SPTXN2, S = –1000** or **s_ptx_N2 = –1000** for input values:

Single phase region: $p > 22000$ bar or $p < 0.00001$ bar or
(x = –1) $t > 726.85$°C or $t < -146.958$ °C or $t < t_{mel}(p)$

Saturation lines: at p = –1000 and t > -146.958 °C   or $t < -209.999$ °C
(x = 0 or x = 1)   at t = –1000 and p > 33.958 bar or $p < 0.00001$ bar or
                        at $p < 33.958$ bar or $p > 0.00001$ bar
                          and $|t-t_s(p)| > 0.1$ K

References: [2]

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

Function Name: **t_ph_N2**

Sub-program with function value: **REAL*8 FUNCTION TPHN2(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

TPHN2, T or **t_ph_N2** - Temperature t in °C

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the calculation of wet steam

The wet steam region is calculated automatically. That means the given values of p and h are taken as a basis and the subprogram will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. When calculating wet steam the value for x has to be calculated. If the state point to be calculated is located in the single-phase region x = - 1 has to be entered.

Results for wrong input values

Result **TPHN2, T = –1000** or **t_ph_N2 = –1000** for input values:

Single phase region: $p > 22000$ bar or $p < 0.00001$ bar or
($x = -1$) $t > 726.85$°C or $t < -146.958$ °C or $t < t_{mel}(p)$

Saturation lines: at p = –1000 and t > -146.958 °C   or $t < -209.999$ °C
($x = 0$ or $x = 1$)   at t = –1000 and p > 33.958 bar or $p < 0.00001$ bar or
                            at $p < 33.958$ bar or $p > 0.00001$ bar
                               and $|t-t_s(p)| > 0.1$ K

References: [2]

Melting Temperature t_{mel} = f(p)

Function Name: **tmel_p_N2**

Sub-program with function value: **REAL*8 FUNCTION TMELPN2(P)**
for call from Fortran REAL*8 TMELP,P

Input values

P - Pressure p in bar

Result

TMELPN2, **T** or **tmel_p_N2** – Melting temperature t_{mel} in °C

Range of validity

Pressure: from 0.00001 bar to 22000 bar

Results for wrong input values

Result **TMELPN2, T = –1000** or **tmel_p_N2 = –1000** for input values:
  p < 0.00001 bar or p > 22000 bar

References: [1], [2]

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

Function Name: **t_ps_N2**

Sub-program with function value: **REAL*8 FUNCTION TPSN2(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

   TPSN2, T or **t_ps_N2** - Temperature t in °C

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the calculation of wet steam

The wet steam region is calculated automatically. That means the given values of p and h are taken as a basis and the subprogram will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. When calculating wet steam the value for x has to be calculated. If the state point to be calculated is located in the single-phase region x = - 1 has to be entered.

Results for wrong input values

Result **TPSN2, T = –1000** or **t_ps_N2 = –1000** for input values:

Single phase region: $p > 22000$ bar or $p < 0.00001$ bar or
($x = -1$) $t > 726.85$°C or $t < $ -146.958 °C or $t < t_{mel}(p)$

Saturation lines: at p = –1000 and t > -146.958 °C   or $t < -209.999$ °C
($x = 0$ or $x = 1$)   at t = –1000 and p > 33.958 bar or $p < 0.00001$ bar or
                        at $p < 33.958$ bar or $p > 0.00001$ bar
                           and $|t$-$t_S(p)| > 0.1$ K

References: [2]

Saturation Temperature t_s = f(p)

Function Name: **ts_p_N2**

Sub-program with function value: **REAL*8 FUNCTION TSPN2(P)**
for call from Fortran   REAL*8 P

Input values

   P - Pressure p in bar

Result

   TSPN2, **T** or **ts_p_N2** - Saturation temperature t_s in °C

Range of validity

from $p_t = 0.00001$ bar to $p_c = 33.958$ bar

Results for wrong input values

Result **TSPN2, T = –1000** or **ts_p_N2 = –1000** for input values:
   $p < 0.00001$ bar or $p > 33.958$ bar

References: [2]

Specific Internal Energy $u = \mathrm{f}(p,t,x)$

Function Name: **u_ptx_N2**

Sub-program with function value: **REAL*8 FUNCTION UPTXN2(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 - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

    UPTXN2, U or **u_ptx_N2** - Specific internal energy u in kJ/kg

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the vapor fraction x and on the calculation of wet steam

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

Single-phase region

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

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for *x*. It is adequate to enter either the given value for t and p = –1000, or the given value for p and t = –1000, plus the value for *x* between 0 and 1. When *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Wet steam region of LibN2: t_t = -209.999 °C   ... p_t = 0.12523 bar   (t – triple point)

                                        t_c = -146.958 °C   ... p_c = 33.958   bar   (c – critical point)

Results for wrong input values

Result **UPTXN2, U = –1000** or **u_ptx_N2 = –1000** for input values:

Single phase region: $p > 22000$ bar   or $p < 0.00001$ bar or
(x = –1) $t > 726.85°C$ or $t < -146.958$ °C or $t < t_{mel}(p)$

Saturation lines: at p = –1000   and   t > -146.958 °C   or $t < -209.999$ °C
(x = 0 or x = 1)   at t = –1000   and   p > 33.958 bar   or $p < 0.00001$ bar or
                        at $p < 33.958$ bar   or $p > 0.00001$ bar
                         and $|t\text{-}t_s(p)| > 0.1$ K

References: [1], [2]

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

Function Name: **v_ptx_N2**

Sub-program with function value: **REAL*8 FUNCTION VPTXN2(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 - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

   VPTXN2, **V** or **v_ptx_N2** - Specific volume v in m^3/kg

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the vapor fraction x and on the calculation of wet steam

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

Single-phase region

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

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for x. It is adequate to enter either the given value for t and p = –1000, or the given value for p and t = –1000, plus the value for x between 0 and 1. When p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Wet steam region of LibN2: t_t = -209.999 °C   ... p_t = 0.12523 bar   (t – triple point)

                                   t_c = -146.958 °C   ... p_c = 33.958 bar   (c – critical point)

Results for wrong input values

Result **VPTXN2, V = –1000** or **v_ptx_N2 = –1000** for input values:

Single phase region: p > 22000 bar or p < 0.00001 bar or
(x = –1) t > 726.85°C or t < -146.958 °C or $t < t_{mel}(p)$

Saturation lines: at p = –1000 and t > -146.958 °C   or t < -209.999 °C
(x = 0 or x = 1)   at t = –1000 and p > 33.958 bar or p < 0.00001 bar or
                        at p < 33.958 bar or p > 0.00001 bar
                          and $|t-t_s(p)|$ > 0.1 K

References: [1], [2]

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

Function Name: **w_ptx_N2**

Sub-program with function value: **REAL*8 FUNCTION WPTXN2(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 - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

WPTXN2, W or **w_ptx_N2** - Isentropic speed of sound w in m/s

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the vapor fraction *x* and on the calculation of wet steam

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

Single-phase region

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

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for x. It is adequate to enter either the given value for t and p = −1000, or the given value for p and t = −1000, plus the value for x between 0 and 1. When p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in −1000.

(Wet steam region of LibN2: t_t = -209.999 °C   ... p_t = 0.12523 bar   (t – triple point)

                                       t_c = -146.958 °C   ... p_c = 33.958   bar   (c – critical point)

Results for wrong input values

Result **WPTXN2, W = −1000** or **w_ptx_N2 = −1000** for input values:

Single phase region: $p > 22000$ bar or $p < 0.00001$ bar or
(x = −1) $t > 726.85$°C or $t < -146.958$ °C or $t < t_{mel}(p)$

Saturation lines: at p = −1000 and t > -146.958 °C   or $t < -209.999$ °C
(x = 0 or x = 1)   at t = −1000 and p > 33.958 bar or $p < 0.00001$ bar or
                          at $p < 33.958$ bar or $p > 0.00001$ bar
                            and $|t\text{-}t_s(p)| > 0.1$ K

References: [1], [2]

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

Function Name: **x_ph_N2**

Sub-program with function value: **REAL*8 FUNCTION XPHN2(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

XPHN2, X or **x_ph_N2** - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the calculation of wet steam

The wet steam region is calculated automatically. That means the given values of p and h are taken as a basis and the subprogram will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. When calculating wet steam the value for x has to be calculated. If the state point to be calculated is located in the single-phase region x = - 1 has to be entered.

Results for wrong input values

Result **XPHN2, X = –1** or **x_ph_N2 = –1** for input values:

if the state point is located in the single phase region

p > 33.958 bar or p < 0.00001 bar

References: [1], [2]

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

Function Name: **x_ps_N2**

Sub-program with function value: **REAL*8 FUNCTION XPSN2(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

    XPSN2, X or **x_ps_N2** - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the calculation of wet steam

The wet steam region is calculated automatically. That means the given values of p and h are taken as a basis and the subprogram will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. When calculating wet steam the value for x has to be calculated. If the state point to be calculated is located in the single-phase region x = - 1 has to be entered.

Results for wrong input values

Result **XPSN2, X = –1** or **x_ps_N2 = –1** for input values:

    if the state point is located in the single phase region

    $p > 33.958$ bar or $p < 0.00001$ bar

References: [1], [2]

Compression factor *z* = f(*p,t,x*)

Function Name: **z_ptx_N2**

Sub-program with function value: **REAL*8 FUNCTION ZPTXN2(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 - Vapor fraction *x* in (kg saturated steam)/(kg wet steam)

Result

     ZPTXN2, Z or **z_ptx_N2** - Isentropic speed of sound *w* in m/s

Range of validity

Temperature: from 63.151 K (-209.999°C) to 1000 K (726.85°C)

Pressure: from 0.00001 bar to 22000 bar

Details on the vapor fraction *x* and on the calculation of wet steam

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

Single-phase region

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

Wet-steam region

When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for *x*. It is adequate to enter either the given value for t and p = –1000, or the given value for p and t = –1000, plus the value for *x* between 0 and 1. When *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Wet steam region of LibN2: t_t = -209.999 °C   ... p_t = 0.12523 bar   (t – triple point)

                                      t_c = -146.958 °C   ... p_c = 33.958   bar   (c – critical point)

Results for wrong input values

Result   **ZPTXN2, Z = –1000**   or   **z_ptx_N2 = –1000**   for input values:

Single phase region: *p* > 22000 bar   or   *p* < 0.00001 bar or
(*x* = –1)   *t* > 726.85°C   or   *t* < -146.958 °C or $t < t_{mel}(p)$

Saturation lines: at p = –1000   and   t > -146.958 °C   or   *t* < -209.999 °C
(*x* = 0 or *x* = 1)   at t = –1000   and   p > 33.958 bar   or   *p* < 0.00001 bar or
                        at *p* < 33.958 bar   or   *p* > 0.00001 bar
                        and $|t\text{-}t_s(p)|$ > 0.1 K

References: [1], [2]

KCE-ThermoFluidProperties
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KCE ThermoFluidProperties

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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)
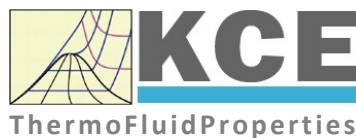
KCE

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.

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KCE ThermoFluidProperties

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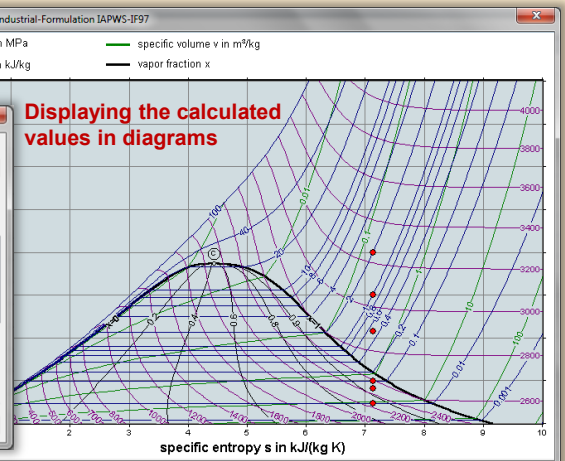## Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

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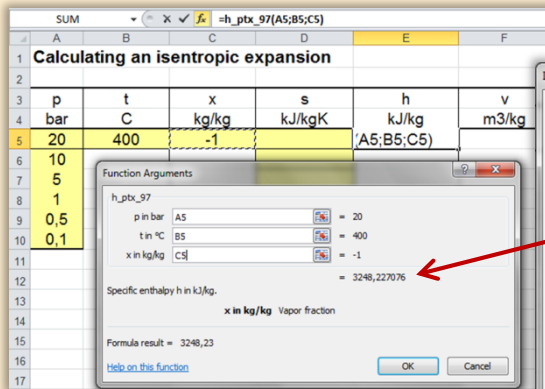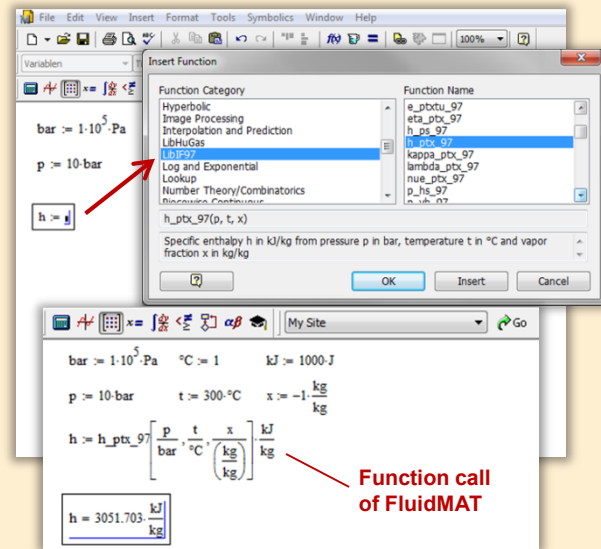
Choosing a property library and a function
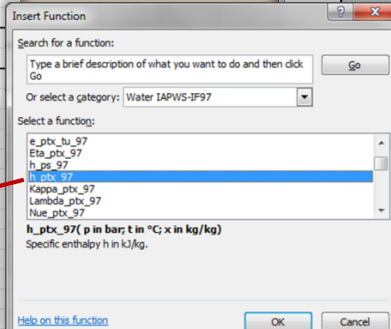
Displaying the calculated values in diagrams
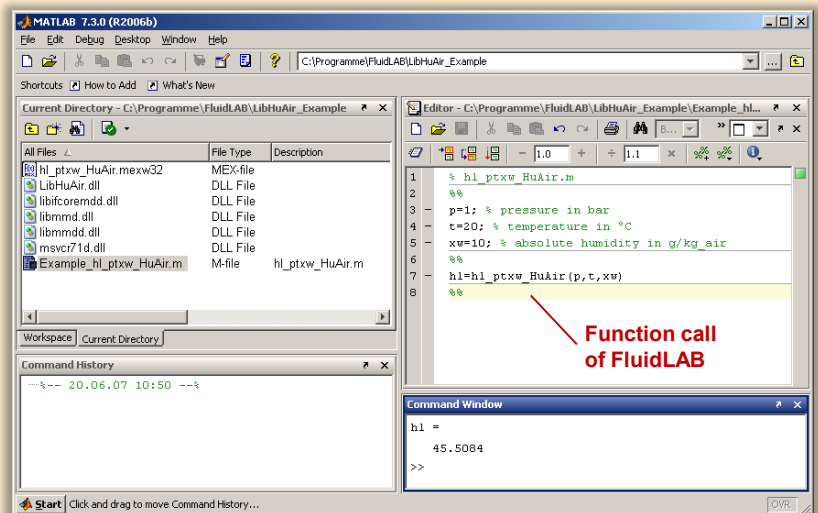
Menu for the input of given property values

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™.
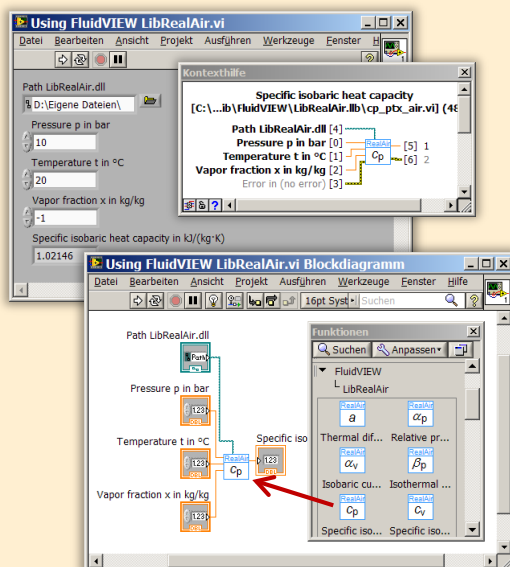
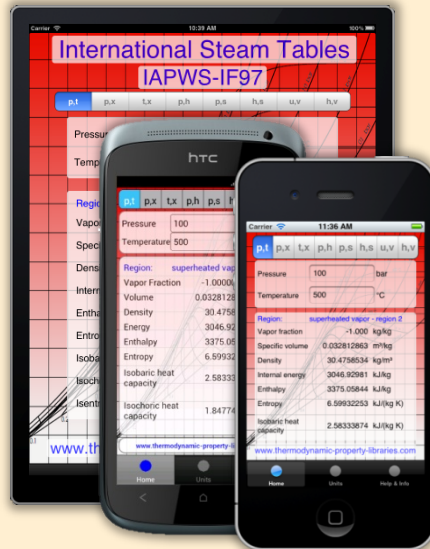### Add-On FluidDYM for DYMOLA® (Modelica) and SimulationX®

The property functions can be called in DYMOLA® and SimulationX®.
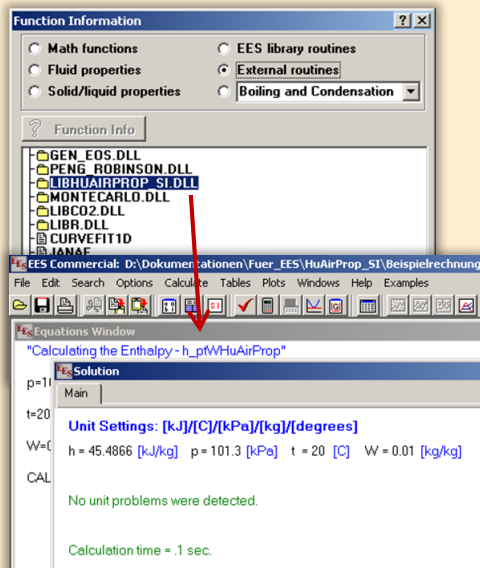
Property Software for Pocket Calculators

FluidCasio

fx 9750 G II

CFX 9850
fx-GG20

CFX 9860 G
Graph 85

ALGEBRA
FX 2.0

FluidHP

HP 48   HP 49

FluidTI

TI Voyage 200

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

For more information please contact:

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Mobile: +49-172-7914607
Fax: +49-3222-1095810

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

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

www.thermofluidprop.com

5. References

[1]   Lemmon, E., W.; Jacobsen, R, T: *Viscosity and Thermal Conductivity Equations for Nitrogen, Oxygen, Argon and Air*, 2004.

[2]   Span, R.; Lemmon, E. W.; Jacobsen, R, T; Wagner, W; Yokozeki, A: *Journal of Physical and Chemical Reference Data, Volume 29, No. 6,* 2000.

6. Satisfied Customers

Period from 2018 to 2022

The following companies and institutions use the property libraries:

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

- FluidLAB for MATLAB® and Simulink

- FluidMAT for Mathcad®

- FluidPRIME for Mathcad Prime®

- FluidEES for Engineering Equation Solver® EES

- FluidDYM for Dymola® (Modelica) and SimulationX®

- FluidVIEW for LabVIEW™

- FluidPYT for Python

- FluidJAVA for Java

- DLLs for Windows Applications

- Shared Objects for Linux

- Shared Objects for macOS.

2022

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

Wärme, Hamburg
ILK, Dresden
Stricker IB, Küssnacht a. Rigi, Switzerland
LEAG, Cottbus   05/2022
RWE Supply & Trading, Essen
IGT Tomalla, Kreuztal
B+T Engineering, Dübendorf, Switzerland
Stricker IB, Küssnacht a. Rigi, Switzerland
Vogelsang & Benning, Bochum   04/2022
Frischli, Rehburg-Loccum
BPS Consulting, 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