Property Library for
Nitrous Oxide

FluidEXL *Graphics*
with LibN2O
for Excel®

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Software for the Calculation of the Properties
of Nitrous Oxide
Including DLL and Add-In for Excel®
FluidEXL *Graphics*
LibN2O

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_LibN2O_x64.zip

including the following folders an files:

\FLUFT\

\Formulation97\

FluidEXL_Graphics_LibN2O_Docu_Eng.pdf

FluidEXL_Graphics_Eng.xla

LC.dll

LibN2O.dll

LibN2O.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_LibN2O.zip

including the following folders and files:

\FLUFT\

\Formulation97\

FluidEXL_Graphics_LibN2O_Docu_Eng.pdf

FluidEXL_Graphics_Eng.xla

LC.dll

LibN2O.dll

LibN2O.chm.

1. Property Functions

Functional Dependence	Function Name	Call from Fortran Program	Property or Function	Unit of the Result
$a = f(p,t,x)$	a_ptx_N2O	A_PTX_N2O(P,T,X)	Thermal diffusivity	m²/s
$c_p = f(p,t,x)$	cp_ptx_N2O	CP_PTX_N2O(P,T,X)	Specific isobaric heat capacity	kJ/(kg K)
$c_v = f(p,t,x)$	cv_ptx_N2O	CV_PTX_N2O(P,T,X)	Specific isochoric heat capacity	kJ/(kg K)
$\eta = f(p,t,x)$	eta_ptx_N2O	ETA_PTX_N2O(P,T,X)	Dynamic viscosity	Pa . s
$h = f(p,t,x)$	h_ptx_N2O	H_PTX_N2O(P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p,t,x)$	ka_ptx_N2O	KA_PTX_N2O(P,T,X)	Isentropic exponent	-
$\lambda = f(p,t,x)$	lam_ptx_N2O	LAM_PTX_N2O(P,T,X)	Thermal conductivity	W/(m . K)
$\nu = f(p,t,x)$	ny_ptx_N2O	NY_PTX_N2O(P,T,X)	Kinematic viscosity	m²/s
$Pr = f(p,t,x)$	pr_ptx_N2O	PR_PTX_N2O(P,T,X)	*Prandtl*-number	-
$p_s = f(t)$	ps_t_N2O	PS_T_N2O(T)	Vapor pressure from temperature	bar
$\rho = f(p,t,x)$	rho_ptx_N2O	RHO_PTX_N2O(P,T,X)	Density	kg/m³
$s = f(p,t,x)$	s_ptx_N2O	S_PTX_N2O(P,T,X)	Specific entropy	kJ/(kg K)
$\sigma = f(t)$	sigma_t_N2O	SIGMA_T_N2O(T)	Surface tension from temperature	N/m
$t = f(p,h)$	t_ph_N2O	T_PH_N2O(P,H)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p,s)$	t_ps_N2O	T_PS_N2O(P,S)	Backward function: Temperature from pressure and entropy	°C
$t_s = f(p)$	ts_p_N2O	TS_P_N2O(P)	Saturation temperature from pressure	°C
$u = f(p,t,x)$	u_ptx_N2O	U_PTX_N2O(P,T,X)	Specific internal energy	kJ/kg
$v = f(p,t,x)$	v_ptx_N2O	V_PTX_N2O(P,T,X)	Specific volume	m³/kg
$w = f(p,t,x)$	w_ptx_N2O	W_PTX_N2O(P,T,X)	Isentropic speed of sound	m/s
$x = f(p,h)$	x_ph_N2O	X_PH_N2O(P,H)	Backward function: Vapor fraction from pressure and enthalpy	kg/kg
$x = f(p,s)$	x_ps_N2O	X_PS_N2O(P,S)	Backward function: Vapor fraction from pressure and entropy	kg/kg

Units: t in °C

           p in bar

           x in (kg saturated steam)/(kg wet steam)

Range of validity

Temperature range: from - 90.82 °C to 251.85 °C
Pressure range: from   0.8784 bar to 500 bar

Reference state

h = 0 kJ/kg   and s = 0 kJ/(kg K)   at p = 1,01325 bar on the saturated liquid line (x = 0)

Details on the vapor fraction *x*

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.

Wet-steam region

If the state point to be calculated is located in the wet steam region, a value for *x* 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*. When calculating wet steam either the given value for *t* and p = -1000 or the given value for *p* and t = -1000 and in both cases the value for *x* between 0 and 1 must be entered.

If *p* and *t* and *x* are entered as given values, the program considers *p* and *t* to be appropriate to represent the vapor pressure curve. If this is not the case the calculation for the property of the chosen function results in −1.

Wet steam region: Temperature ranges from t_{min} = - 90.82 °C to t_c = 36.37 °C

                Pressure ranges from p_{min} = 0.8784 bar to p_c = 72.447 bar

Note:

If the input values are located outside the range of validity, the calculated function will always result in −1000. Please find more exact details on every function and its corresponding range of validity in the enclosed program documentation in Chapter 3.

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 LibN2O 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_LibN2O_x64_Eng.zip   (for 64 bit version)

or

   CD_FluidEXL_Graphics_LibN2O_Eng.zip"   (for 32 bit version).

you will see the folder

   \CD_FluidEXL_Graphics_LibN2O_x64_Eng\   (for 64 bit version)

or

   \CD_FluidEXL_Graphics_LibN2O_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_LibN2O_Docu_Eng
   LC.dll
   LibN2O.dll
   LibN2O.chm
   Reg_.reg

Now, please copy the following folders and files

   \FLUFT\
   \Formulation97\
   FluidEXL_Graphics_Eng.xla
   LibN2O.dll
   LibN2O.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)
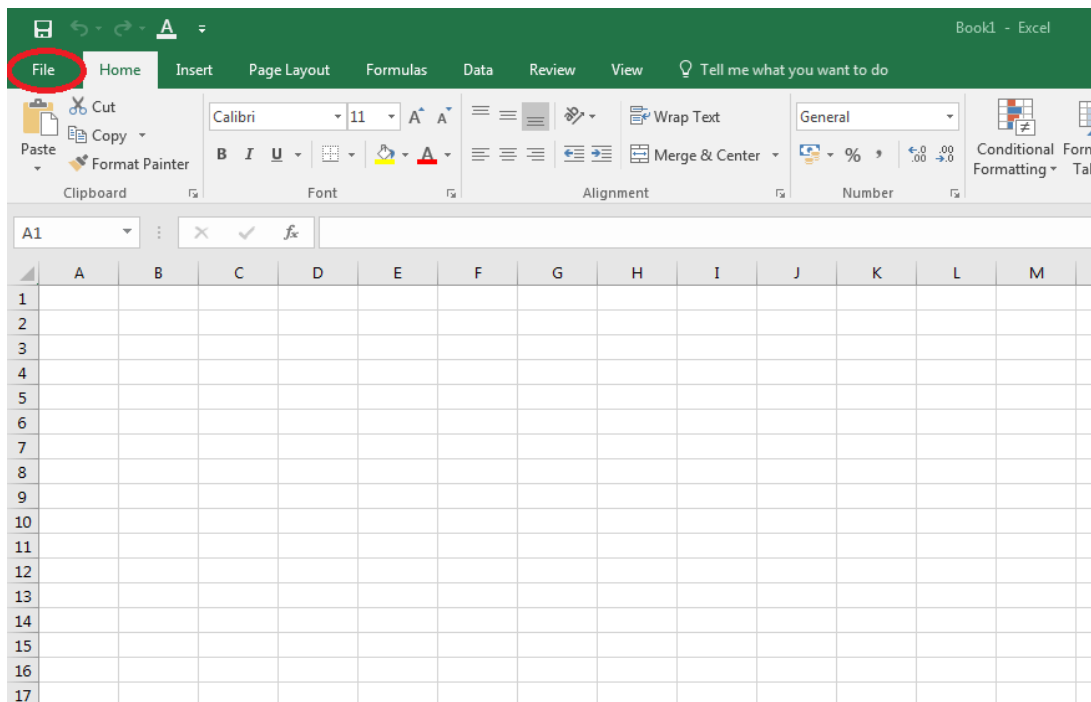

Figure 2.1: Registering FluidEXL*Graphics* as Add-In in Excel® 2016

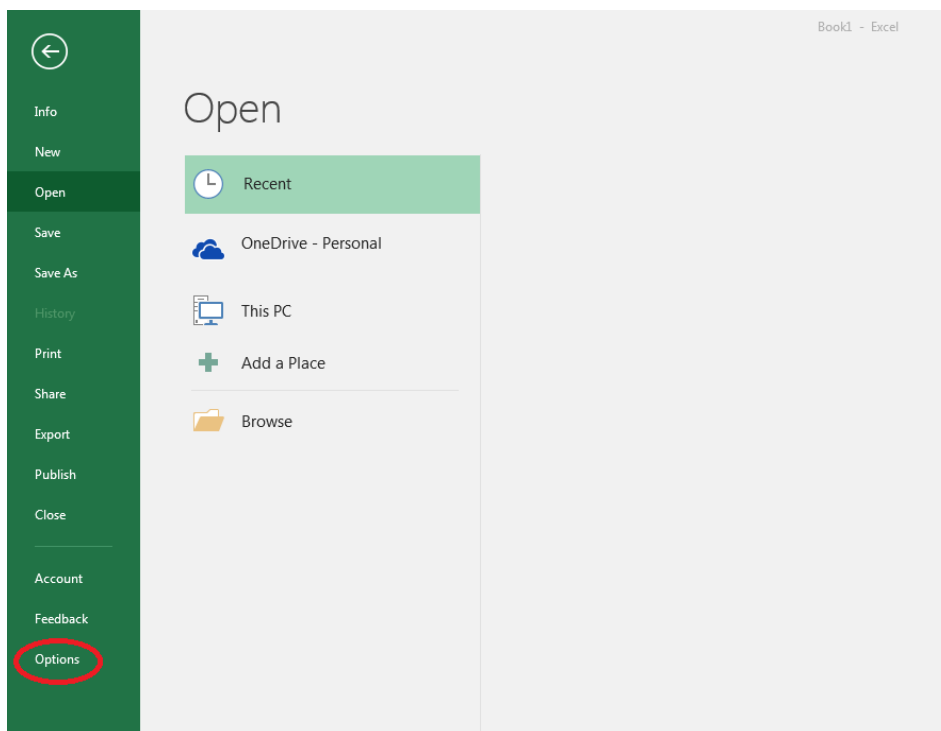- Click on the "Options" button in the menu which appears (see Fig. 2.2)

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

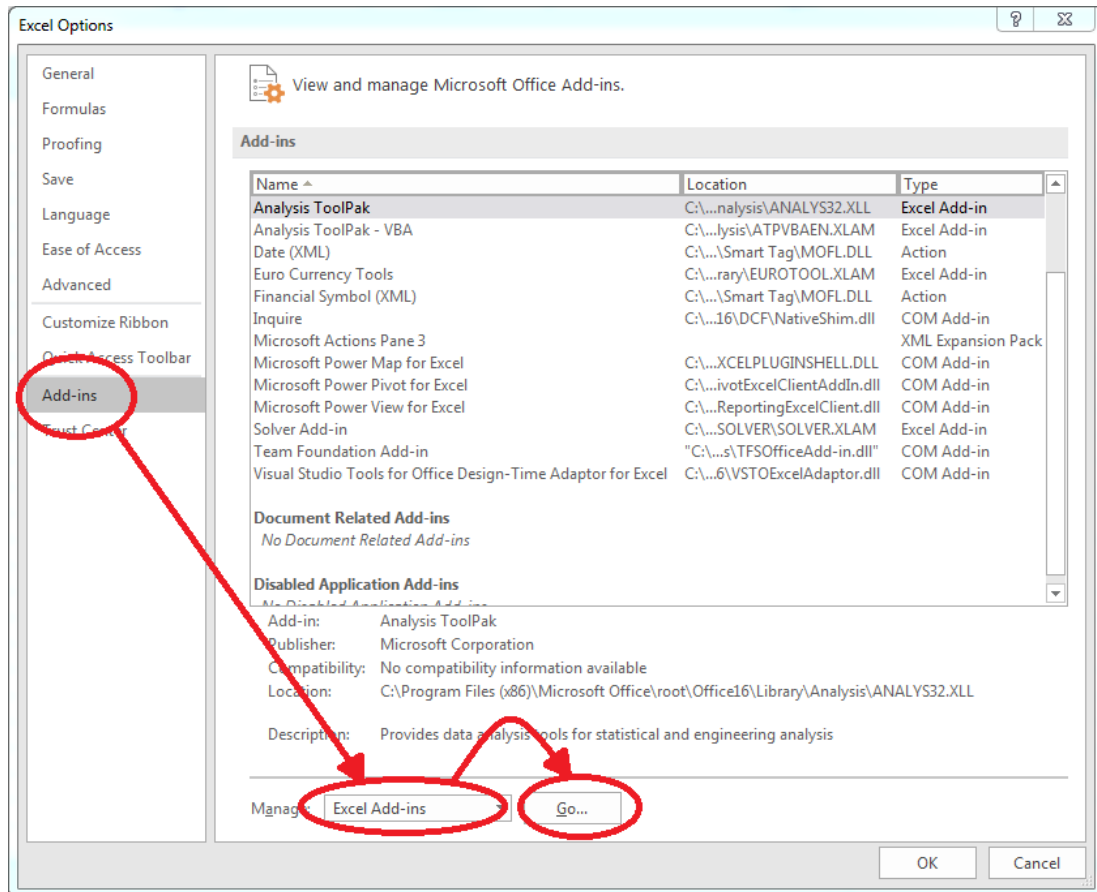- Click on "Add-Ins" in the next menu (Fig. 2.3)

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)
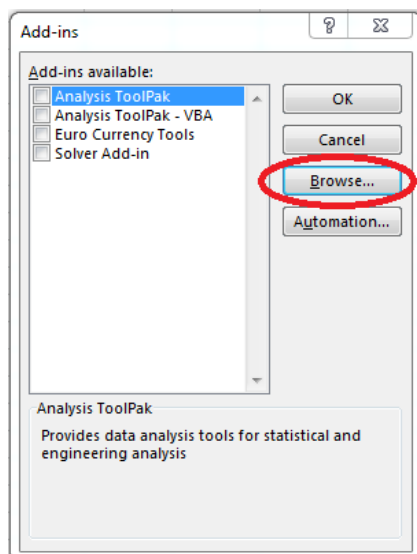

Figure 2.4: Dialog window "Add-ins"

- 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.
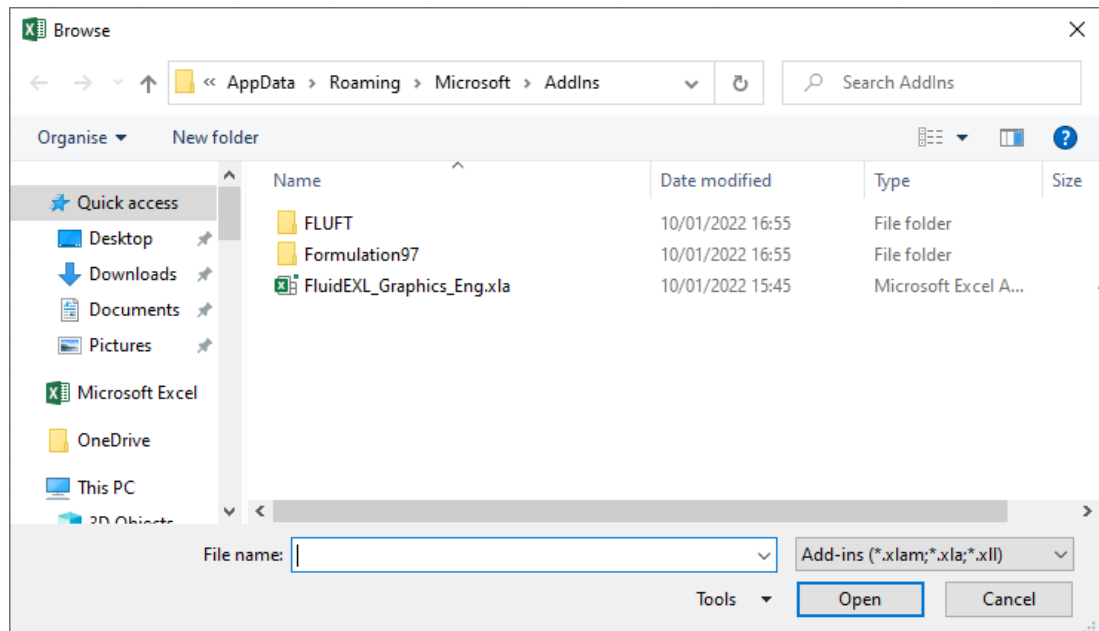

Figure 2.5: "Browse"-Window

  > 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
  >> LibN2O.dll
  >> LibN2O.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).
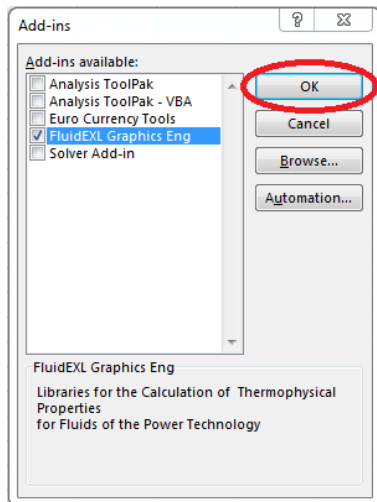
Figure 2.6: Dialog window "Add-Ins"

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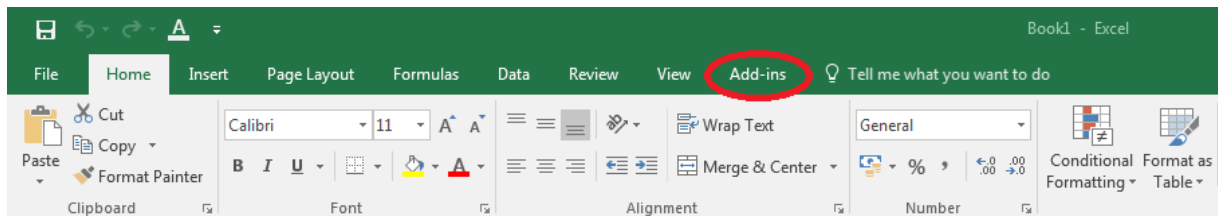
Figure 2.7: Menu item "Add-Ins"

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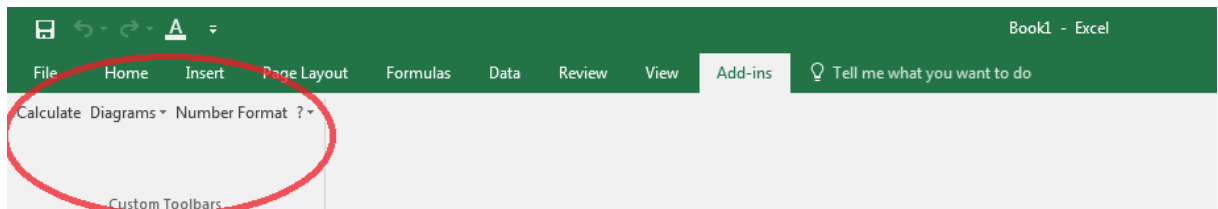
Figure 2.8: FluidEXL^{Graphics} menu bar

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

An example calculation of "LibN2O" DLL library property functions can be found in chapter 2.4.

2.3 Licensing the LibN2O Property LibN2Orary

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).
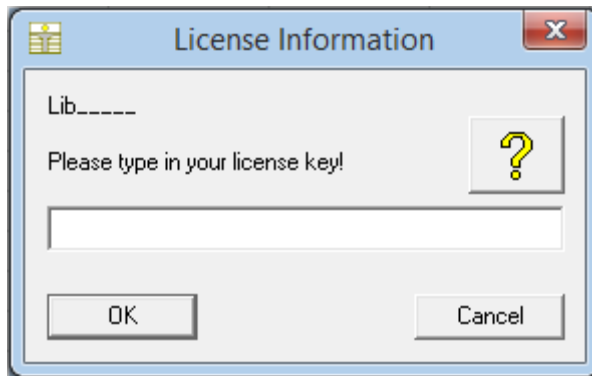
Figure 2.12: "License Information" window

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:
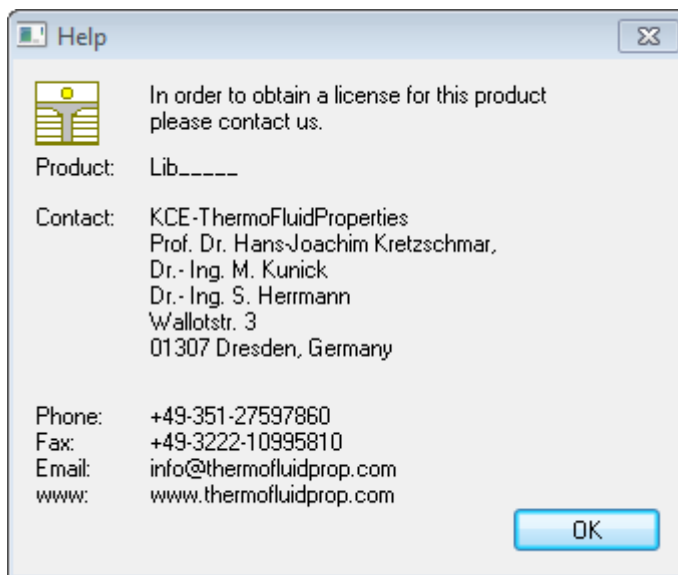
Figure 2.13: "Help" window

If you do not enter a valid license it is still possible to start Excel® by clicking "Cancel" twice. In this case, the LibN2O 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 LibN2O property library, you have to delete the files

    LibN2O.dll
    LibN2O.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 "LibN2O_ _ _ _ _ in Figure 2.12 and 2.13 stands for the LibN2Orary you are installing. In this case it is the LibN2O 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: p_t = 0.8784 bar to 500 bar)

   $\Rightarrow$ e. g.: Enter the value 10 into cell A2

- Enter a value for t in °C in a cell
(Range of validity: t = - 90.82 °C to 251.85 °C)

   $\Rightarrow$ e. g.: Enter the value 200 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.

   Wet-steam 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.
   If the state point to be calculated is located in the wet steam region, a value for x between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered.
   When calculating wet steam either the given value for t and p = -1000 or the given value for p and t = -1000 and in both cases the value for x between 0 and 1 must be entered.
   If p <u>and</u> t <u>and</u> x are entered as given values, the program considers p and t to be appropriate to represent the vapor pressure curve.

   (Vapor-pressure curve of nitrous oxide: t_{min} = - 90.82 °C to t_c = 36.37 °C

   p_{min} = 0.8784 bar to p_c = 72.447 bar

   $\Rightarrow$ 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 Figure 2.14).
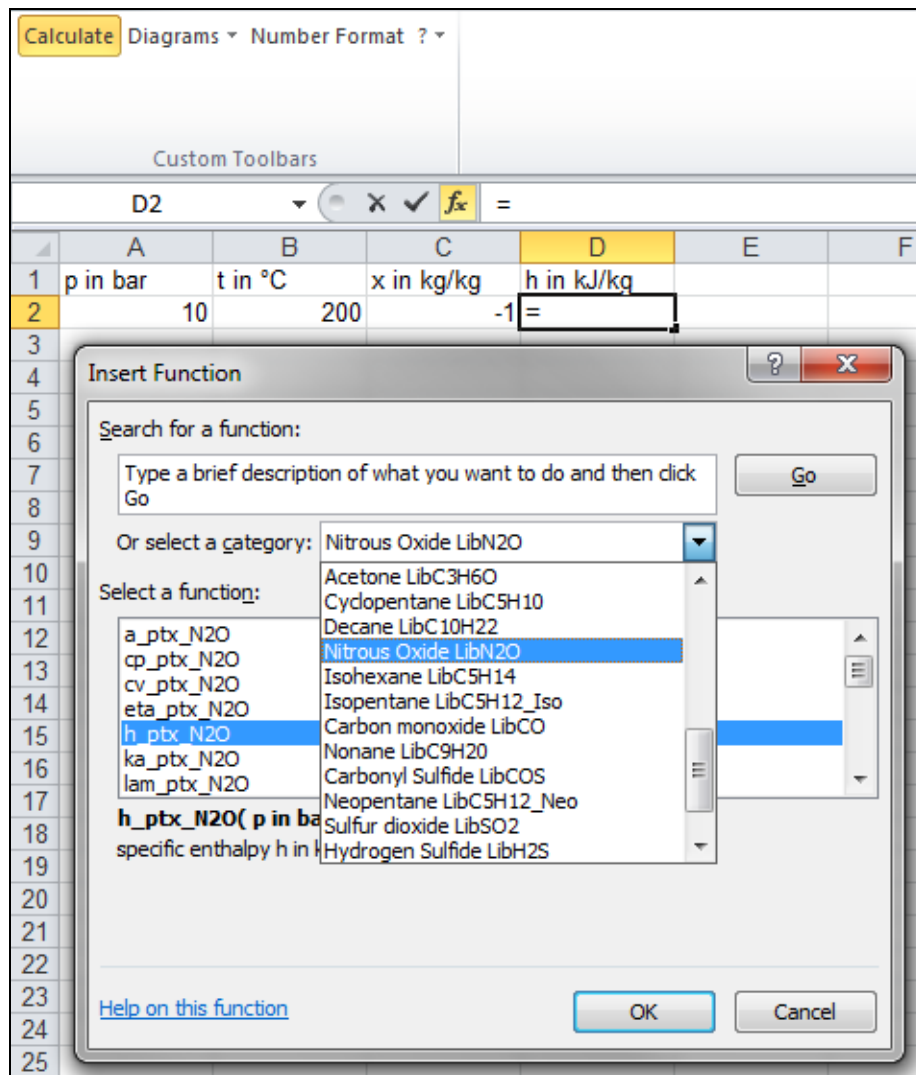
Figure 2.14: Choice of library and function name

- Search and click the "Nitrous Oxide LibN2O" library under "Or select a category:" in the upper part of the window.

- Search and click the h_ptx_N2O 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 "p"

- 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:
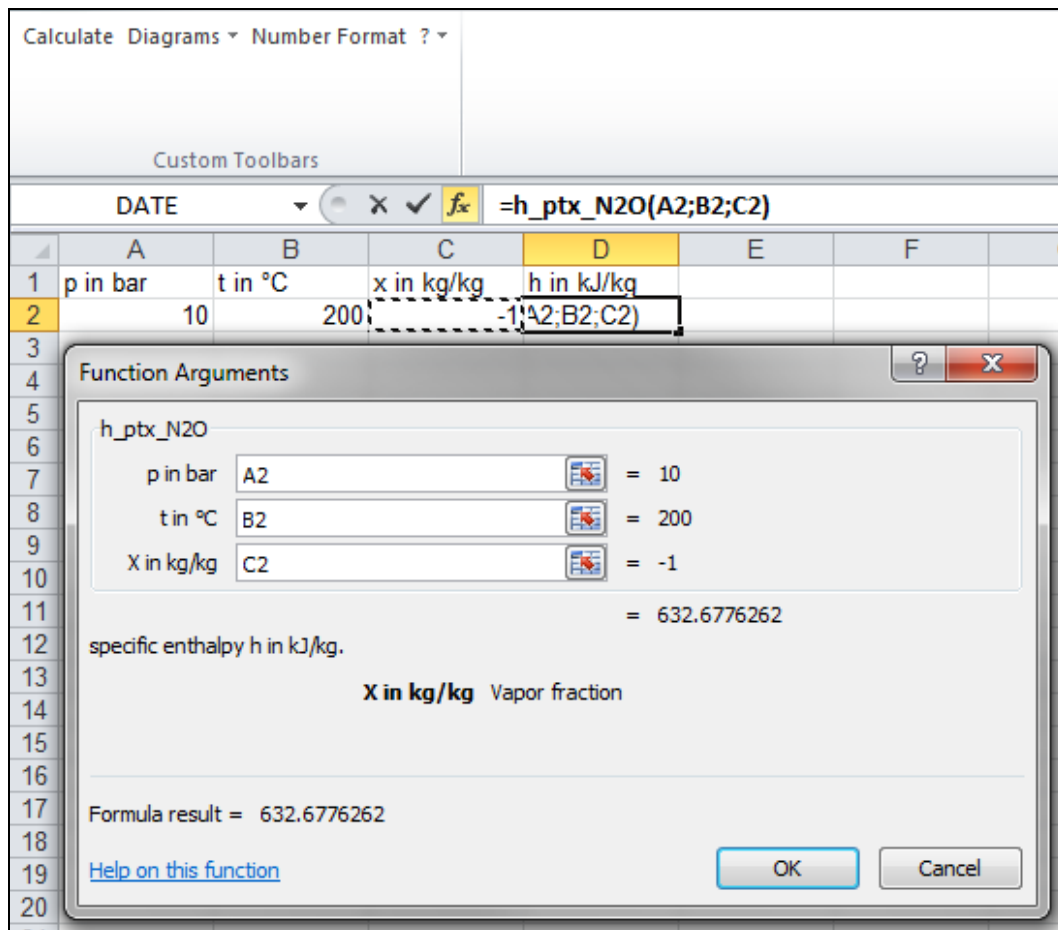
Figure 2.16: Input menu showing the result

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

  ⇒ The result for *h* in our sample calculation here is: 632.6776262 kJ/kg.

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

Note:

If the calculation results in –1000, this indicates that the values entered are located outside the range of validity shown in Chapter 1. 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 "LibN2O" 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.
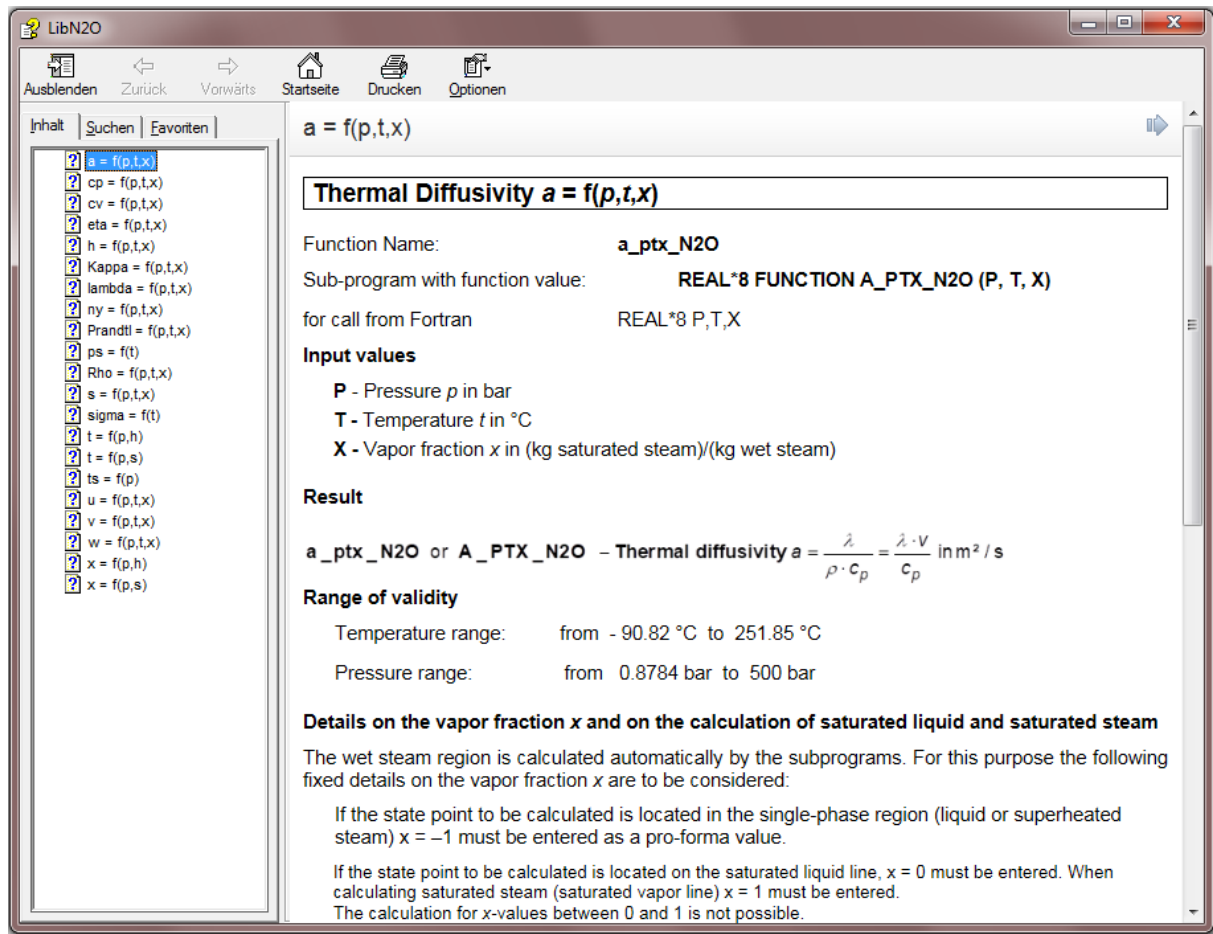
Figure 2.17: Help Window

If the LibN2O.chm function help cannot be found, you will be redirected to a Microsoft® help website by your standard browser. In this case, the LibN2O.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 LibN2O Library

Should you wish to remove <u>only</u> the LibN2O library, delete the files

LibN2O.dll
LibN2O.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
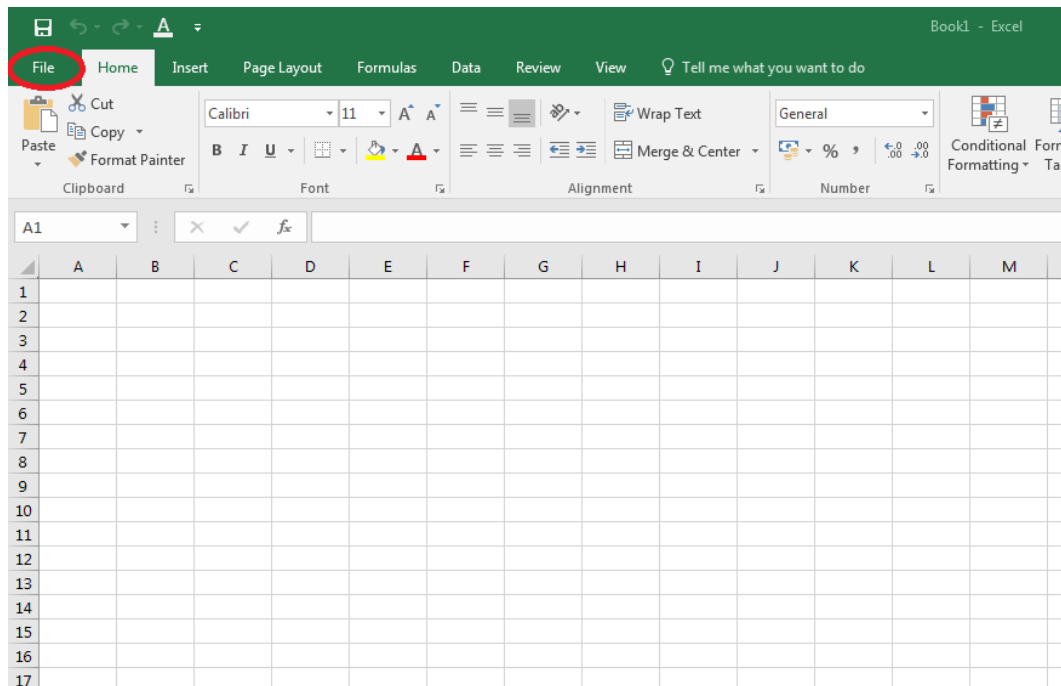
Figure 2.18: Unregistering FluidEXL^{Graphics} as Add-In in Excel® 2016
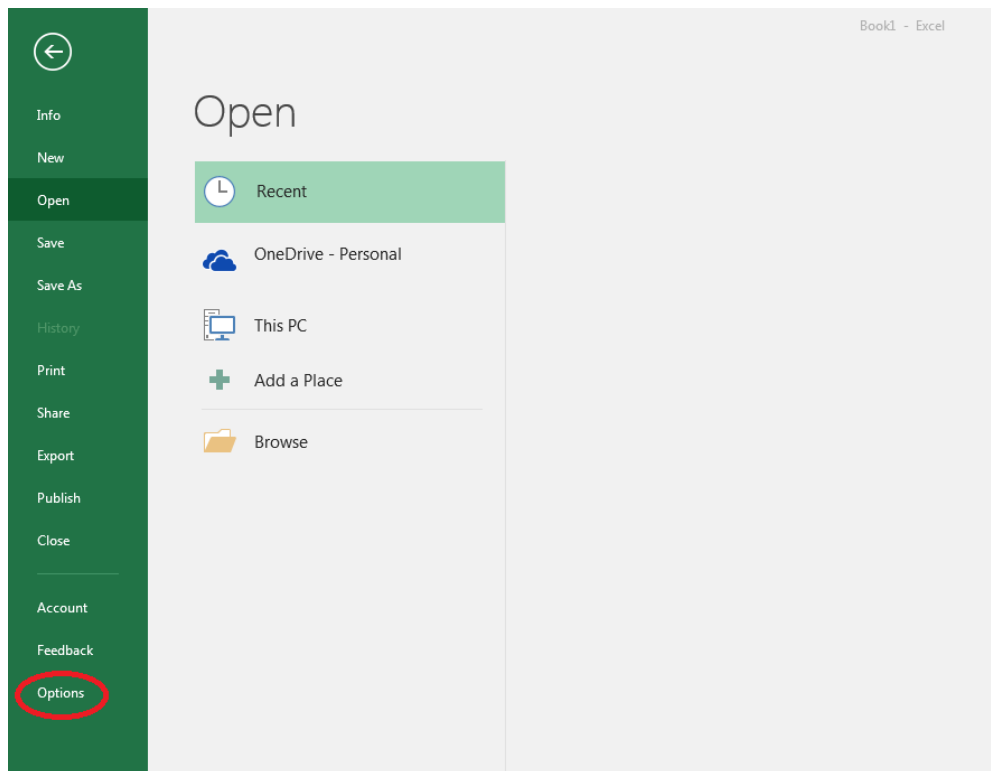
Figure 2.19 Unregistering FluidEXL*Graphics* as Add-In in Excel® 2016

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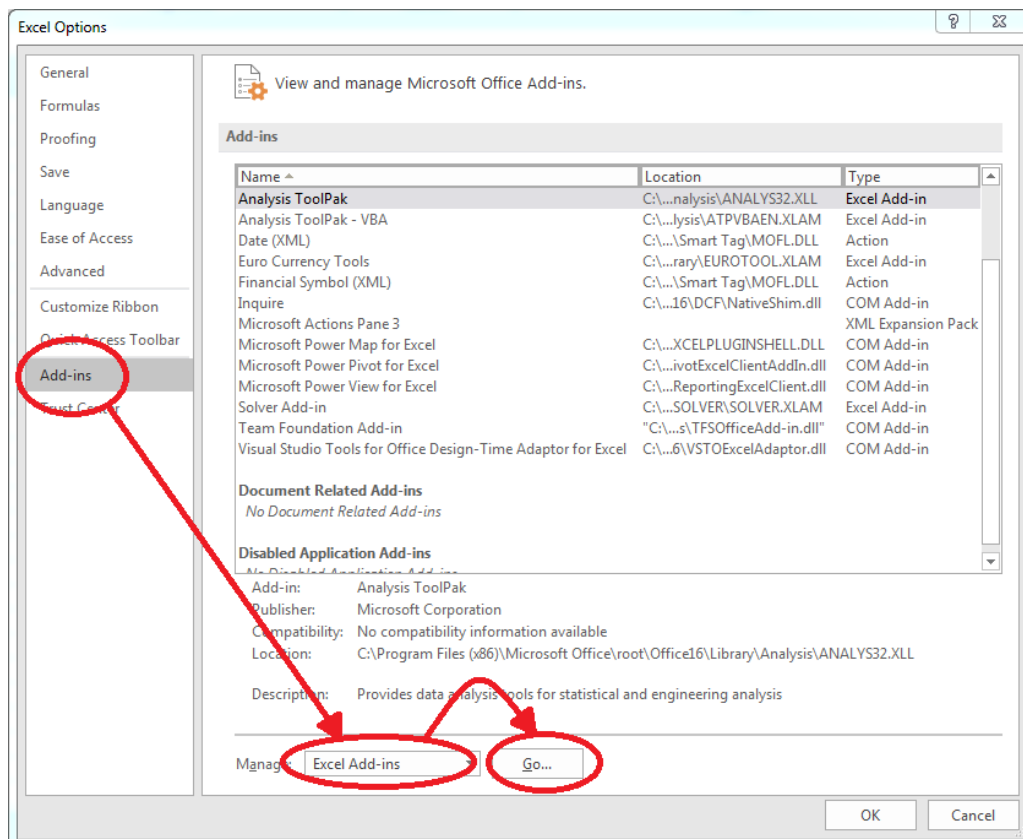
Figure 2.20: Dialog window "Add-Ins"

- 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

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

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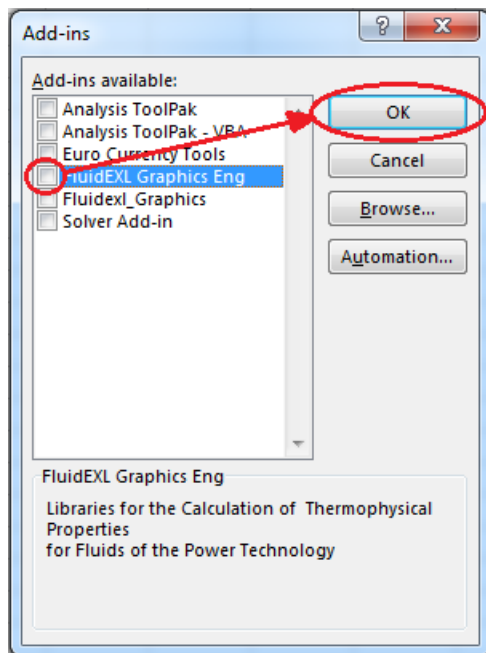
Figure 2.21: Dialog window "Add-Ins"

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

LibN2O.dll
LibN2O.chm

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

C:\Program Files\FluidEXL_Graphics_Eng

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

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

"FluidEXL Graphics Eng"

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

Now FluidEXL^{Graphics} has been removed.

3. Program Documentation

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

Function Name: **a_ptx_N2O**

Sub-program with function value: **REAL*8 FUNCTION A_PTX_N2O (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

a_ptx_N2O or **A_PTX_N2O** – **Thermal diffusivity** $a = \dfrac{\lambda}{\rho \cdot c_p} = \dfrac{\lambda \cdot v}{c_p}$ in m²/s

Range of validity

Temperature range: from - 90.82 °C to 251.85 °C
Pressure range: from 0.8784 bar to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated steam

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

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

If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered.
The calculation for x-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, 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 (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Wet steam region : Temperature ranges from $t_{min} = -90.82\ °C$ to $t_c = 36.37\ °C$

Pressure ranges from $p_{min} = 0.8784\ \text{bar}$ to $p_c = 72.447\ \text{bar}$

Results for wrong input values

Result **A_PTX_N2O = –1000 or a_ptx_N2O = –1000** for input values:

Single phase region:
Liquid or overheated steam (x = –1):
 - at p < 0.8784 bar or p > 500 bar
 - at t < - 90.82 °C or t > 251.85 °C

Wet steam region (0 ≤ x ≤ 1):
 - at 0 < x < 1 , i.e. calculation in the wet steam region not possible!
 - at $p = -1000$ bar and $t < t_{min}$ or $t > t_c$
 - at $t = -1000$ bar and $p < p_{min}$ or $p > p_c$
 - at $p < p_{min}$ or $p > p_c$ or at $t < t_{min}$ or $t > t_c$

References: [1], [3], [4], [5], [6]

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

Function Name: **cp_ptx_N2O**

Sub-program with function value: **REAL*8 FUNCTION CP_PTX_N2O (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
cp_ptx_N2O or CP_PTX_N2O - Specific isobaric heat capacity cp in kJ/ (kg K)

Range of validity

Temperature range: from - 90.82 °C to 251.85 °C
Pressure range: from   0.8784 bar to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated steam

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

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

If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered.
The calculation for x-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, 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 (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Wet steam region :   Temperature ranges from $t_{min} = -90.82$ °C to $t_c = 36.37$ °C
Pressure ranges from $p_{min} = 0.8784$ bar to $p_c = 72.447$ bar

Results for wrong input values

Result **CP_PTX_N2O = –1000 or cp_ptx_N2O = –1000** for input values:

Single phase region:
Liquid or overheated steam (x = –1):
 - at p < 0.8784 bar or p > 500 bar
 - at t < - 90.82 °C or t > 251.85 °C

Wet steam region (0 ≤ x ≤ 1):
 - at 0 < x < 1 , i.e. calculation in the wet steam region not possible!
 - at $p = -1000$ bar and $t < t_{min}$ or $t > t_c$

 - at $t = -1000$ bar and $p < p_{min}$ or $p > p_c$

 - at $p < p_{min}$ or $p > p_c$ or at $t < t_{min}$ or $t > t_c$

References: [1]

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

Function Name: **cv_ptx_N2O**

Sub-program with function value: **REAL*8 FUNCTION CV_PTX_N2O (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
cv_ptx_N2O or CV_PTX_N2O - Specific isochoric heat capacity cv in kJ/ (kg K)

Range of validity

Temperature range: from - 90.82 °C to 251.85 °C
Pressure range: from   0.8784 bar to 500 bar

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

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

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

If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered.
The calculation for *x*-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, 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* (x = 0 or x = 1). If *p* and *t* and *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the vapor pressure curve.

Wet steam region :   Temperature ranges from t_{min} = -90.82 °C to t_c = 36.37 °C

Pressure ranges from p_{min} = 0.8784 bar to p_c = 72.447 bar

Results for wrong input values

Result **CV_PTX_N2O = –1000 or cv_ptx_N2O = –1000** for input values:

Single phase region:
  Liquid or overheated steam (x = –1):
   - at p < 0.8784 bar or p > 500 bar
   - at t < - 90.82 °C or t > 251.85 °C

Wet steam region (0 ≤ x ≤ 1):
    - at 0 < x < 1 , i.e. calculation in the wet steam region not possible!
    - at $p = -1000$ bar and $t < t_{min}$ or $t > t_c$

    - at $t = -1000$ bar and $p < p_{min}$ or $p > p_c$

    - at $p < p_{min}$ or $p > p_c$ or at $t < t_{min}$ or $t > t_c$

References: [1]

Dynamic Viscosity η = f(p,t,x)

Function Name: **eta_ptx_N2O**

Sub-program with function value: **REAL*8 FUNCTION ETA_PTX_N2O (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
eta_ptx_N2O or ETA_PTX_N2O - Dynamic viscosity η in Pa s

Range of validity

Temperature range: from - 90.82 °C to 251.85 °C
Pressure range: from 0.8784 bar to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated steam

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

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

If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered.
The calculation for x-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, 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 (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Wet steam region : Temperature ranges from t_{min} = -90.82 °C to t_c = 36.37 °C

Pressure ranges from p_{min} = 0.8784 bar to p_c = 72.447 bar

Results for wrong input values

Result **ETA_PTX_N2O = –1000 or eta_ptx_N2O = –1000** for input values:

Single phase region:
Liquid or overheated steam (x = –1):
- at p < 0.8784 bar or p > 500 bar
- at t < - 90.82 °C or t > 251.85 °C

Wet steam region (0 ≤ x ≤ 1):
- at 0 < x < 1 , i.e. calculation in the wet steam region not possible!
- at $p = -1000$ bar and $t < t_{min}$ or $t > t_c$

- at $t = -1000$ bar and $p < p_{min}$ or $p > p_c$

- at $p < p_{min}$ or $p > p_c$ or at $t < t_{min}$ or $t > t_c$

References: [1], [3], [4], [5], [6]

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

Function Name: **h_ptx_N2O**

Sub-program with function value: **REAL*8 FUNCTION H_PTX_N2O (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
h_ptx_N2O or H_PTX_N2O – specific enthalpy h in kJ/kg

Range of validity

   Temperature range: from - 90.82 °C to 251.85 °C
   Pressure range: from   0.8784 bar to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated steam

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

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

   If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered.
   The calculation for x-values between 0 and 1 is not possible.

   When calculating saturated liquid or saturated steam, 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 (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

   Wet steam region :   Temperature ranges from $t_{min} = -90.82$ °C to $t_c = 36.37$ °C
                   Pressure ranges from $p_{min} = 0.8784$ bar to $p_c = 72.447$ bar

Results for wrong input values

Result **H_PTX_N2O = –1000 or h_ptx_N2O = –1000** for input values:

Single phase region:
   Liquid or overheated steam (x = –1):
    - at p < 0.8784 bar or p > 500 bar
    - at t < - 90.82 °C or t > 251.85 °C

Wet steam region (0 ≤ x ≤ 1):
    - at x < 0 or x > 1
    - at $p = -1000$ bar and $t < t_{min}$ or $t > t_c$

    - at $t = -1000$ bar and $p < p_{min}$ or $p > p_c$

    - at $p < p_{min}$ or $p > p_c$ or at $t < t_{min}$ or $t > t_c$

References: [1]

Isentropic Exponent κ = f(p,t,x)

Function Name: **ka_ptx_N2O**

Sub-program with function value: **REAL*8 FUNCTION KA_PTX_N2O (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
ka_ptx_N2O or KA_PTX_N2O – Isentropic exponent κ

Range of validity

Temperature range: from - 90.82 °C to 251.85 °C
Pressure range: from   0.8784 bar to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated steam

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

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

If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered.
The calculation for x-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, 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 (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Wet steam region :   Temperature ranges from t_{min} = -90.82 °C to t_c = 36.37 °C

Pressure ranges from p_{min} = 0.8784 bar to p_c = 72.447 bar

Results for wrong input values

Result **KA_PTX_N2O = –1000 or ka_ptx_N2O = –1000** for input values:

Single phase region:
    Liquid or overheated steam (x = –1):
      - at p < 0.8784 bar or p > 500 bar
      - at t < - 90.82 °C or t > 251.85 °C

Wet steam region (0 ≤ x ≤ 1):
      - at 0 < x < 1 , i.e. calculation in the wet steam region not possible!
      - at $p = -1000$ bar and $t < t_{min}$ or $t > t_c$

      - at $t = -1000$ bar and $p < p_{min}$ or $p > p_c$

      - at $p < p_{min}$ or $p > p_c$ or at $t < t_{min}$ or $t > t_c$

References: [1]

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

Function Name:	**lam_ptx_N2O**
Sub-program with function value: for call from Fortran	**REAL*8 FUNCTION LAM_PTX_N2O (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
lam_ptx_N2O or LAM_PTX_N2O – Thermal conductivity λ in W/ (m K)

Range of validity

Temperature range:	from - 90.82 °C to 251.85 °C
Pressure range:	from 0.8784 bar to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated steam

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

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

If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered.
The calculation for x-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, 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 (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Wet steam region :	Temperature ranges from $t_{min} = -90.82\ °C$ to $t_c = 36.37\ °C$
	Pressure ranges from $p_{min} = 0.8784$ bar to $p_c = 72.447$ bar

Results for wrong input values

Result **LAM_PTX_N2O = –1000 or lam_ptx_N2O = –1000** for input values:

Single phase region:
Liquid or overheated steam (x = –1):
  - at p < 0.8784 bar or p > 500 bar
  - at t < - 90.82 °C or t > 251.85 °C

Wet steam region (0 ≤ x ≤ 1):
  - at 0 < x < 1 , i.e. calculation in the wet steam region not possible!
  - at $p = -1000$ bar and $t < t_{min}$ or $t > t_c$
  - at $t = -1000$ bar and $p < p_{min}$ or $p > p_c$
  - at $p < p_{min}$ or $p > p_c$ or at $t < t_{min}$ or $t > t_c$

References: [1], [3], [4], [5], [6]

Kinematic Viscosity ν = f(p,t,x)

Function Name: **ny_ptx_N2O**

Sub-program with function value: **REAL*8 FUNCTION NY_PTX_N2O (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
ny_ptx_N2O or NY_PTX_N2O – kinematic viscosity v in m²/s

Range of validity

   Temperature range: from - 90.82 °C to 251.85 °C
   Pressure range: from   0.8784 bar to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated steam

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

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

   If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered.
   The calculation for x-values between 0 and 1 is not possible.

   When calculating saturated liquid or saturated steam, 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 (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

   Wet steam region :   Temperature ranges from t_{min} = -90.82 °C to t_c = 36.37 °C
                               Pressure ranges from p_{min} = 0.8784 bar to p_c = 72.447 bar

Results for wrong input values

Result **NY_PTX_N2O = –1000 or ny_ptx_N2O = –1000** for input values:

Single phase region:
   Liquid or overheated steam (x = –1):
     - at p < 0.8784 bar or p > 500 bar
     - at t < - 90.82 °C or t > 251.85 °C

Wet steam region (0 ≤ x ≤ 1):
     - at 0 < x < 1 , i.e. calculation in the wet steam region not possible!
     - at $p = -1000$ bar and $t < t_{min}$ or $t > t_c$

     - at $t = -1000$ bar and $p < p_{min}$ or $p > p_c$

     - at $p < p_{min}$ or $p > p_c$ or at $t < t_{min}$ or $t > t_c$

References: [1], [3], [4], [5], [6]

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

Function Name: **pr_ptx_N2O**

Sub-program with function value: **REAL*8 FUNCTION PR_PTX_N2O (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

Pr _ptx _N2O or PR _PTX _N2O – Prandtl number $Pr = \dfrac{\eta \cdot c_p}{\lambda}$

Range of validity

Temperature range: from - 90.82 °C to 251.85 °C
Pressure range: from   0.8784 bar to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated steam

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

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

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.
The calculation for x-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, 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 ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Wet steam region :   Temperature ranges from $t_{min} = -90.82\ °C$ to $t_c = 36.37\ °C$

Pressure ranges from $p_{min} = 0.8784\ \text{bar}$ to $p_c = 72.447\ \text{bar}$

Results for wrong input values

Result **PR_PTX_N2O = –1000 or Pr_ptx_N2O = –1000** for input values:

Single phase region:
Liquid or overheated steam ($x = -1$):
  - at p < 0.8784 bar or p > 500 bar
  - at t < - 90.82 °C or t > 251.85 °C

Wet steam region ($0 \leq x \leq 1$):
  - at 0 < x < 1 , i.e. calculation in the wet steam region not possible!
  - at $p = -1000$ bar and $t < t_{min}$ or $t > t_c$

  - at $t = -1000$ bar and $p < p_{min}$ or $p > p_c$

  - at $p < p_{min}$ or $p > p_c$ or at $t < t_{min}$ or $t > t_c$

References: [1], [3], [4], [5], [6]

Vapor Pressure p_s = f(t)

Function Name: **ps_t_N2O**

Sub-program with function value: **REAL*8 FUNCTION PS_T_N2O (T)**
for call from Fortran REAL*8 T

Input values

T - Temperature t in °C

Result

ps_t_N2O or PS_T_N2O - Vapor pressure p_s in bar

Range of validity

Temperature range: from t_{min} = -90.82 °C to t_c = 36.37 °C

Results for wrong input values

Result **PS_T_N2O = –1000 or ps_t_N2O = –1000** for input values:

Wet steam region (0 ≤ x ≤ 1):

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

References: [1]

Density ρ = f(*p,t,x*)

Function Name:	**rho_ptx_N2O**
Sub-program with function value: for call from Fortran	**REAL*8 FUNCTION RHO_PTX_N2O (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
rho_ptx_N2O or RHO_PTX_N2O - Density ρ in kg/m³

Range of validity

Temperature range:	from - 90.82 °C to 251.85 °C
Pressure range:	from 0.8784 bar to 500 bar

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

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

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

If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered.
The calculation for *x*-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, 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* (x = 0 or x = 1). If *p* and *t* and *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the vapor pressure curve.

Wet steam region :   Temperature ranges from $t_{min} = -90.82\ °C$ to $t_c = 36.37\ °C$

Pressure ranges from $p_{min} = 0.8784$ bar to $p_c = 72.447$ bar

Results for wrong input values

Result **RHO_PTX_N2O = –1000 or rho_ptx_N2O = –1000** for input values:

Single phase region:
Liquid or overheated steam (x = –1):
  - at p < 0.8784 bar or p > 500 bar
  - at t < - 90.82 °C or t > 251.85 °C

Wet steam region (0 ≤ x ≤ 1):
  - at x < 0 or x > 1
  - at $p = -1000$ bar and $t < t_{min}$ or $t > t_c$

  - at $t = -1000$ bar and $p < p_{min}$ or $p > p_c$

  - at $p < p_{min}$ or $p > p_c$ or at $t < t_{min}$ or $t > t_c$

References: [1]

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

Function Name: **s_ptx_N2O**

Sub-program with function value: **REAL*8 FUNCTION S_PTX_N2O (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
s_ptx_N2O or S_PTX_N2O – specific entropy s in kJ/(kg K)

Range of validity

   Temperature range: from - 90.82 °C to 251.85 °C
   Pressure range: from   0.8784 bar to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated steam

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

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

   If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered.
   The calculation for x-values between 0 and 1 is not possible.

   When calculating saturated liquid or saturated steam, 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 (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

   Wet steam region :   Temperature ranges from $t_{min} = -90.82$ °C to $t_c = 36.37$ °C

                            Pressure ranges from $p_{min} = 0.8784$ bar to $p_c = 72.447$ bar

Results for wrong input values

Result **S_PTX_N2O = –1000 or s_ptx_N2O = –1000** for input values:

Single phase region:
   Liquid or overheated steam (x = –1):
    - at p < 0.8784 bar or p > 500 bar
    - at t < - 90.82 °C or t > 251.85 °C

Wet steam region (0 ≤ x ≤ 1):
    - at x < 0 or x > 1
    - at $p = -1000$ bar and $t < t_{min}$ or $t > t_c$

    - at $t = -1000$ bar and $p < p_{min}$ or $p > p_c$

    - at $p < p_{min}$ or $p > p_c$ or at $t < t_{min}$ or $t > t_c$

References: [1]

Surface Tension σ = f(t)

Function Name: **sigma_t_N2O**

Sub-program with function value: **REAL*8 FUNCTION SIGMA_T_N2O (T)**
for call from Fortran   REAL*8 T

Input values

   T - Temperature t in °C

Result

Sigma_t_N2O or SIGMA_T_N2O – Surface tension σ in N/m

Range of validity

   Temperature range: from $t_{min} = -90.82$ °C to $t_c = 36.37$ °C

Results for wrong input values

Result **SIGMA_T_N2O = –1000 or sigma_t_N2O = –1000** for input values:

Wet steam region (0 ≤ x ≤ 1):

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

References: [2]

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

Function Name: **t_ph_N2O**

Sub-program with function value: **REAL*8 FUNCTION T_PH_N2O (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
t_ph_N2O or T_PH_N2O – Temperature t in °C

Range of validity

Temperature range: from - 90.82 °C to 251.85 °C
Pressure range: from 0.8784 bar to 500 bar

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically. This means that from the given values of p and h the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of t in the appropriate region will be carried out.

Wet steam region : Pressure ranges from p_{min} = 0.8784 bar to p_c = 72.447 bar

Results for wrong input values

Result **T_PH_N2O = –1000 or t_ph_N2O = –1000** for input values:

Single phase region:
Liquid or overheated steam (x = –1):
- at p < 0.8784 bar or p > 500 bar
- at t < - 90.82 °C or t > 251.85 °C

Wet steam region (0 ≤ x ≤ 1):
- at x < 0 or x > 1
- at $p = -1000$ bar and $t < t_{min}$ or $t > t_c$

- at $t = -1000$ bar and $p < p_{min}$ or $p > p_c$

- at $p < p_{min}$ or $p > p_c$ or at $t < t_{min}$ or $t > t_c$

References: [1]

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

Function Name: **t_ps_N2O**

Sub-program with function value: **REAL*8 FUNCTION T_PH_N2O (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
t_ps_N2O or T_PS_N2O – Temperature t in °C

Range of validity

   Temperature range: from - 90.82 °C to 251.85 °C
   Pressure range: from   0.8784 bar to 500 bar

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically. This means that from the given values of p and h the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of t in the appropriate region will be carried out.

   Wet steam region :   Pressure ranges from p_{min} = 0.8784 bar to p_c = 72.447 bar

Results for wrong input values

Result **T_PS_N2O = –1000 or t_ps_N2O = –1000** for input values:

Single phase region:
   Liquid or overheated steam (x = –1):
     - at p < 0.8784 bar or p > 500 bar
     - at t < - 90.82 °C or t > 251.85 °C

Wet steam region (0 ≤ x ≤ 1):
     - at x < 0 or x > 1
     - at $p = -1000$ bar and $t < t_{min}$ or $t > t_c$

     - at $t = -1000$ bar and $p < p_{min}$ or $p > p_c$

     - at $p < p_{min}$ or $p > p_c$ or at $t < t_{min}$ or $t > t_c$

References: [1]

Saturation Temperature $t_s = f(p)$

Function Name: **ts_p_N2O**

Sub-program with function value: **REAL*8 FUNCTION TS_P_N2O (P)**
for call from Fortran   REAL*8 P

Input values

    P - Pressure p in bar

Result

ts_p_N2O or TS_P_N2O - Saturation temperature t_s in °C

Range of validity

    Pressure range: from p_{min} = 0.8784 bar to p_c = 72.447 bar

Results for wrong input values

Result **TS_P_N2O = –1000 or ts_p_N2O = –1000** for input values:

Wet steam region (0 ≤ x ≤ 1):

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

References: [1]

Specific Internal Energy $u = f(p,t,x)$

Function Name: **u_ptx_N2O**

Sub-program with function value: **REAL*8 FUNCTION U_PTX_N2O (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
u_ptx_N2O or U_PTX_N2O – specific internal energy u in kJ/kg

Range of validity

Temperature range: from - 90.82 °C to 251.85 °C
Pressure range: from 0.8784 bar to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated steam

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

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

If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered.
The calculation for x-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, 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 (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Wet steam region : Temperature ranges from $t_{min} = -90.82$ °C to $t_c = 36.37$ °C

Pressure ranges from $p_{min} = 0.8784$ bar to $p_c = 72.447$ bar

Results for wrong input values

Result **U_PTX_N2O = –1000 or u_ptx_N2O = –1000** for input values:

Single phase region:
Liquid or overheated steam (x = –1):
- at p < 0.8784 bar or p > 500 bar
- at t < - 90.82 °C or t > 251.85 °C

Wet steam region (0 ≤ x ≤ 1):
- at x < 0 or x > 1
- at $p = -1000$ bar and $t < t_{min}$ or $t > t_c$

- at $t = -1000$ bar and $p < p_{min}$ or $p > p_c$

- at $p < p_{min}$ or $p > p_c$ or at $t < t_{min}$ or $t > t_c$

References: [1]

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

Function Name: **v_ptx_N2O**

Sub-program with function value: **REAL*8 FUNCTION V_PTX_N2O (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
v_ptx_N2O or V_PTX_N2O – specific volume v in m³/kg

Range of validity

   Temperature range: from - 90.82 °C to 251.85 °C
   Pressure range: from   0.8784 bar to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated steam

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

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

   If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered.
   The calculation for x-values between 0 and 1 is not possible.

   When calculating saturated liquid or saturated steam, 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 (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

   Wet steam region :   Temperature ranges from $t_{min} = -90.82$ °C to $t_c = 36.37$ °C

                          Pressure ranges from $p_{min} = 0.8784$ bar to $p_c = 72.447$ bar

Results for wrong input values

Result **V_PTX_N2O = –1000 or v_ptx_N2O = –1000** for input values:

Single phase region:
   Liquid or overheated steam (x = –1):
    - at p < 0.8784 bar or p > 500 bar
    - at t < - 90.82 °C or t > 251.85 °C

Wet steam region (0 ≤ x ≤ 1):
    - at x < 0 or x > 1
    - at $p = -1000$ bar and $t < t_{min}$ or $t > t_c$

    - at $t = -1000$ bar and $p < p_{min}$ or $p > p_c$

    - at $p < p_{min}$ or $p > p_c$ or at $t < t_{min}$ or $t > t_c$

References: [1]

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

Function Name: **w_ptx_N2O**

Sub-program with function value: **REAL*8 FUNCTION W_PTX_N2O (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
w_ptx_N2O or W_PTX_N2O – isentropic speed of sound w in m/s

Range of validity

   Temperature range: from - 90.82 °C to 251.85 °C
   Pressure range: from 0.8784 bar to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated steam

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

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

   If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.
   The calculation for x-values between 0 and 1 is not possible.

   When calculating saturated liquid or saturated steam, 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 ($x = 0$ or $x = 1$). If 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 vapor pressure curve.

   Wet steam region :   Temperature ranges from $t_{min} = -90.82$ °C to $t_c = 36.37$ °C

                          Pressure ranges from $p_{min} = 0.8784$ bar to $p_c = 72.447$ bar

Results for wrong input values

Result **W_PTX_N2O = –1000 or w_ptx_N2O = –1000** for input values:

Single phase region:
   Liquid or overheated steam ($x = -1$):
    - at p < 0.8784 bar or p > 500 bar
    - at t < - 90.82 °C or t > 251.85 °C

Wet steam region ($0 ≤ x ≤ 1$):
     - at 0 < x < 1 , i.e. calculation in the wet steam region not possible!
     - at $p = -1000$ bar and $t < t_{min}$ or $t > t_c$

     - at $t = -1000$ bar and $p < p_{min}$ or $p > p_c$

     - at $p < p_{min}$ or $p > p_c$ or at $t < t_{min}$ or $t > t_c$

References: [1]

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

Function Name: **x_ph_N2O**

Sub-program with function value: **REAL*8 FUNCTION X_PH_N2O (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
x_ph_N2O or X_PH_N2O – Vapor fraction x in kg/kg

Details on the vapor fraction x and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically. This means that from the given values of p and h the function 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 between 0 and 1 is calculated (0 for saturated liquid, 1 for saturated steam). If the state point to be calculated is located in the single-phase region the result x = - 1 will be returned.

   Wet steam region :   Pressure ranges from p_{min} = 0.8784 bar to p_c = 72.447 bar

Results for wrong input values

Result **X_PH_N2O = –1 or x_ph_N2O = –1** for input values:

   - at x < 0 or x > 1
   - at $p < p_{min}$ or $p > p_c$

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

References: [1]

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

Function Name: **x_ps_N2O**

Sub-program with function value: **REAL*8 FUNCTION X_PH_N2O (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
x_ps_N2O or X_PS_N2O – Vapor fraction x in kg/kg

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically. This means that from the given values of *p* and *h* the function 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 between 0 and 1 is calculated (0 for saturated liquid, 1 for saturated steam). If the state point to be calculated is located in the single-phase region the result x = - 1 will be returned.

Wet steam region :   Pressure ranges from p_{min} = 0.8784 bar to p_c = 72.447 bar

Results for wrong input values

Result **X_PS_N2O = –1 or x_ps_N2O = –1** for input values:

- at x < 0 or x > 1
- at $p < p_{min}$ or $p > p_c$
- at $t < t_{min}$ or $t > t_c$

References: [1]

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**
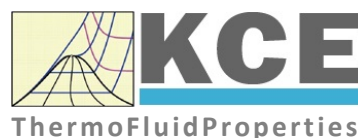
Carbonyl sulfide COS **Library LibCOS**

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:

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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 ν
- Thermal conductivity λ
- Prandtl number Pr
- Thermal diffusivity a

Backward Functions

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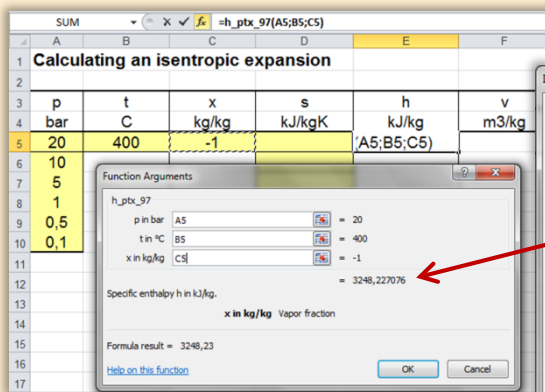- $p, T\ (v,h)$
- $p, T\ (v,u)$

Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

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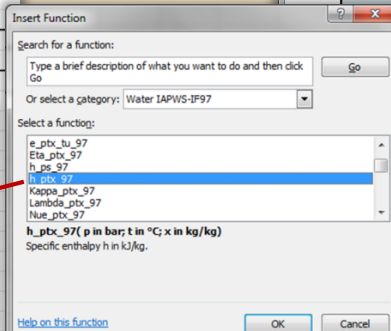
www.thermofluidprop.com

KCE-ThermoFluidProperties
www.thermofluidprop.com

Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

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

Add-In FluidEXL^Graphics for Excel®

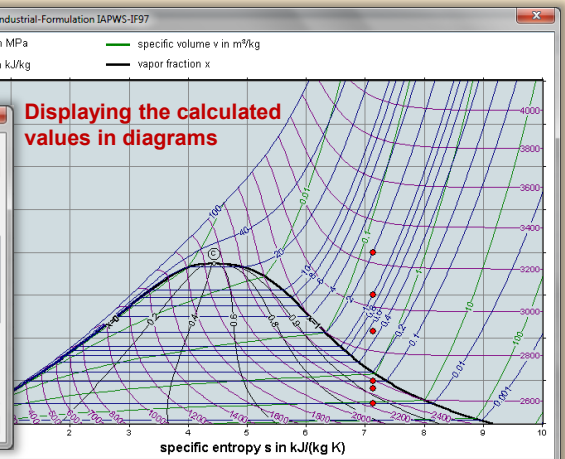Choosing a property library and a function

Displaying the calculated values in diagrams

Menu for the input of given property values

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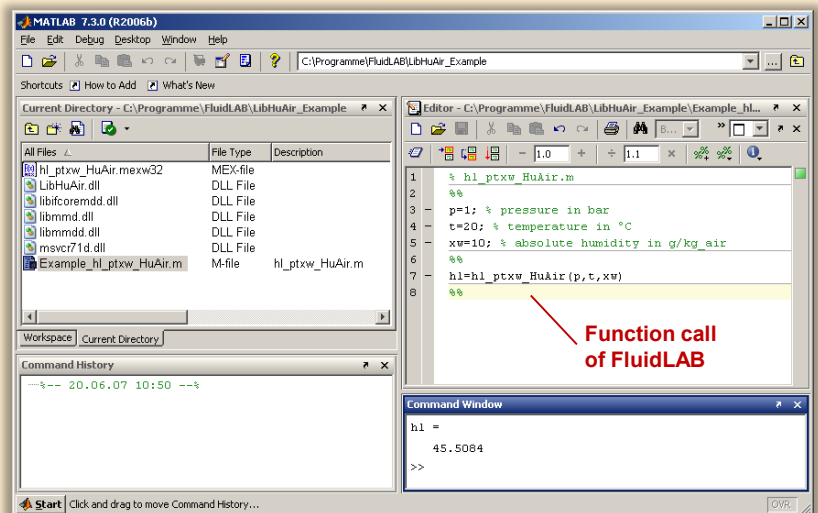### Add-On FluidPRIME for Mathcad Prime®

The property libraries can be used in Mathcad® and Mathcad Prime®.
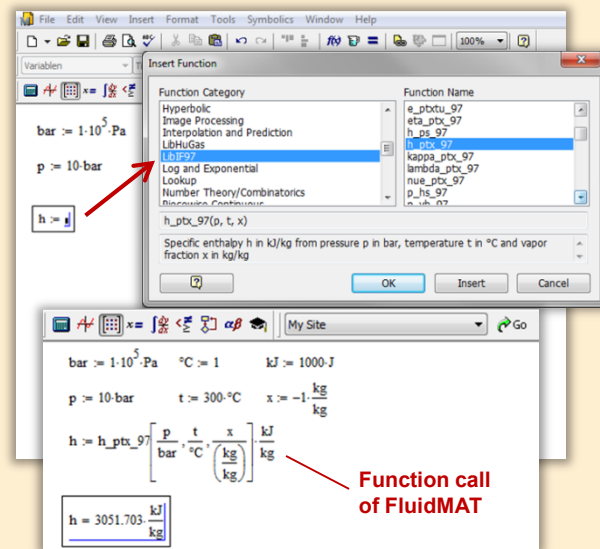
Function call of FluidMAT

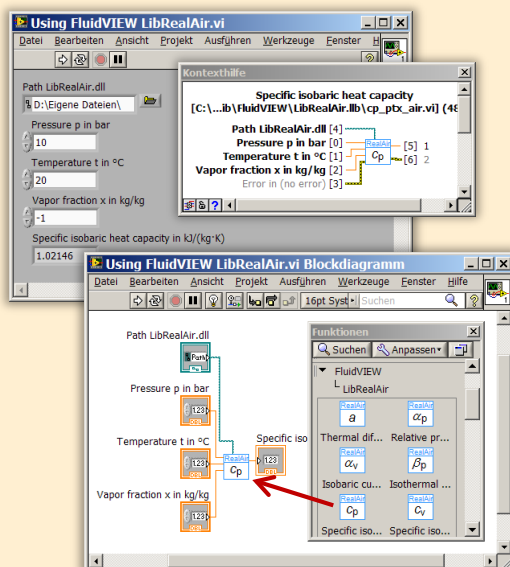### Add-On FluidLAB for MATLAB® and SIMULINK®

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

Function call of FluidLAB
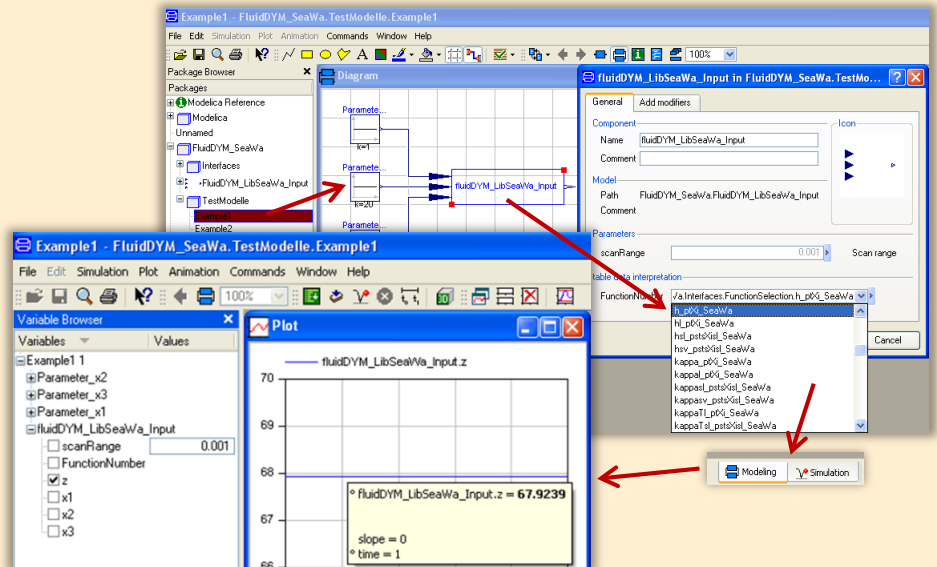
Add-On FluidVIEW for LabVIEW™
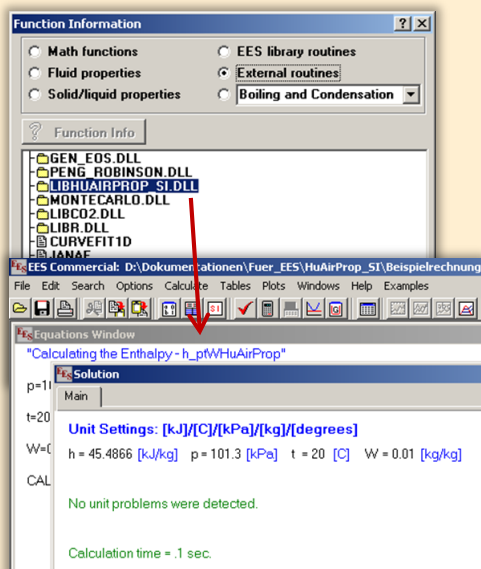
The property functions can be calculated in LabVIEW™.

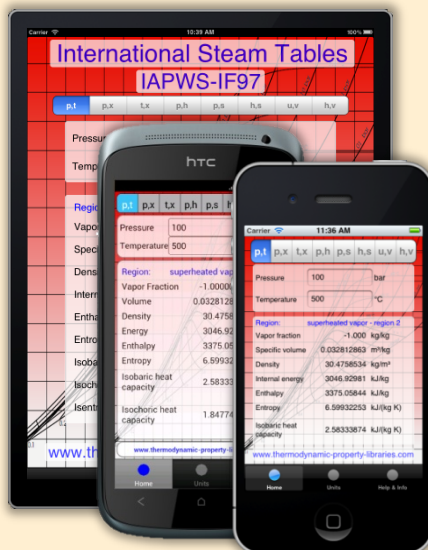### Add-On FluidDYM for DYMOLA® (Modelica) and SimulationX®

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
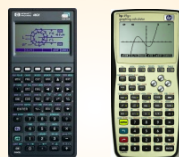
HP 48   HP 49

FluidTI

TI Nspire CX CAS
TI Nspire CAS

TI 83
TI 84
TI 89

TI Voyage 200

TI 92

For more information please contact:

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

Thermodynamic Properties

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

Transport Properties

- Dynamic viscosity η
- Kinematic viscosity ν
- Thermal conductivity λ
- Prandtl number Pr
- 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]   E.W. Lemmon, R. Span:
        Short Fundamental Equation of State for 20 Industrial Fluids
        J.Chem.Eng.Data,51,p.785.850,2006

[2]   A.J. Leadbetter, D.J. Taylor, B. Vincent:
        The densities and surface tension of liquid ethane and nitrous oxide
        Can. J. Chem., 42:2930-2932, 1964

[3]   E.W. Lemmon:
        Personal Communication with E.W. Lemmon, 2012

[4]   M.L. Huber, A. Laeseck, R.A. Perkins,
        Model for the Viscosity and Thermal Conductivity of Refrigerants,
        Including a New Correlation for the Viscosity of R134a
        Ind. Eng. Chem. Res.,42, 3163-3178, 2003

[5]   R. Span, E.W. Lemmon, R.T. Jacobsen, W. Wagner, A. Yokozeki:
        A Reference Equation of State for the Thermodynamic Properties of Nitrogen for
        Temperatures from 63.151 to 1000 K and Pressures to 2200 MPa J. Phys. Chem. Ref.
        Data, 29,1361-1433, 2000

[6]   E.W. Lemmon, R.T. Jacobsen:
        Viscosity and Thermal Conductivity Equations for Nitrogen, Oxygen, Argon, and Air
        Int. J. Thermophys., 25, 21-69, 2004

6. Satisfied Customers

Period from 2018 to 2022

The following companies and institutions use the property libraries:

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

- FluidLAB for MATLAB$^®$ and Simulink

- FluidMAT for Mathcad$^®$

- FluidPRIME for Mathcad Prime$^®$

- FluidEES for Engineering Equation Solver$^®$ EES

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

- FluidVIEW for LabVIEW^{TM}

- FluidPYT for Python

- FluidJAVA for Java

- DLLs for Windows Applications

- Shared Objects for Linux

- Shared Objects for macOS.

2022

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

Wärme, Hamburg

ILK, Dresden

Stricker IB, Küssnacht a. Rigi, Switzerland

LEAG, Cottbus   05/2022

RWE Supply & Trading, Essen

IGT Tomalla, Kreuztal

B+T Engineering, Dübendorf, Switzerland

Stricker IB, Küssnacht a. Rigi, Switzerland

Vogelsang & Benning, Bochum   04/2022

Frischli, Rehburg-Loccum

BPS Consulting, Sprenge   03/2022

HS Hannover, Maschinenbau & BioVT

M+M Turbinentechnik, Bad Salzuflen

Uni. Strathclyde, Glasgow, UK   02/2022

Delta Energy Group, Jiaozhou City, Qingdao, China

Wetzel IB, Guben

Wijbenga, PC Geldermalsen, The Netherlands

Voith Paper, Heidenheim

HS Zittau/Görlitz, Maschinenwesen   01/2022

Thermische Abfallbehandlung, Lauta

Webb Institute, Glen Cove NY, USA

TU Berlin, Umweltverfahrenstechnik

SachsenEnergie, Dresden

Doosan, Chang-won-si, Gyeongsangnam-do, South Korea

KW3, LH Veenendaal, The Netherlands

Université du Luxembourg, Esch-sur-Alzette

Enseleit IB, Mansfeld

Caliqua/Equans, Zürich, Switzerland

Rudnick & Enners, Alpenrod

2021

Wenisch IB, Vetschau   12/2021

PPCHEM, Hinwil, Switzerland

KW3, The Netherlands

BASF Ludwigshafen

Air-Consult, Jena

Sjerp & Jongeneel, RB Zoetermeer, The Netherlands   11/2021

Maerz Ofenbau, Zürich, Switzerland

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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
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Stadtwerke, Neuburg
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ATESTEO, Alsdorf
Hochschule Zittau/Görlitz, Maschinenwesen
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Caverion, Wien, Austria
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Troche Ingenieurbüro, Hayingen   08/2020
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VPC, Vetschau   07/2020
FSK System-Kälte-Klima, Dortmund
Exergie Etudes, Sarl, Switzerland
AWG Wuppertal
STEAG Energy Services, Zwingenberg
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DBI, Leipzig
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Hochschule Darmstadt   04/2020
MTU München CCP
HAW Hamburg   03/2020

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MB-Holding, Vestenbergsgreuth
RWE, Essen
Georg-Büchner-Hochschule, Darmstadt   11/2019
EEB ENERKO, Aldenhoven
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Kehrein & Kubanek Klimatechnik, Moers   10/2019
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2018

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