ThermoFluidProperties

Property Library for Oxygen

FluidEXL*Graphics* with LibO2 for Excel®

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Software for the Calculation of the Properties of Oxygen Including DLL and Add-In for Excel®

FluidEXL*Graphics* LibO2

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_LibO2_x64.zip

including the following folders an files:

\FLUFT\

\Formulation97\

FluidEXL_Graphics_LibO2_Docu_Eng.pdf

FluidEXL_Graphics_Eng.xla

LC.dll

LibO2.dll

LibO2.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_LibO2.zip

including the following folders and files:

\FLUFT\

\Formulation97\

FluidEXL_Graphics_LibO2_Docu_Eng.pdf

FluidEXL_Graphics_Eng.xla

LC.dll

LibO2.dll

LibO2.chm.

1. Program Functions

1.1 Range of Validity

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	50.43 bar
	maximal	P_{max}	818 bar
temperatures:	minimal	$T_{min} = T_t$	-218.789°C
	at critical point	T_c	-118.569°C
	maximal	T_{max}	1726.85°C

The sub-programs of the LibO2 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 LibO2. 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 LibO2, Result as Parameter	Property or Function	Unit of the Result
$a = f(p,t,x)$	a_ptx_O2	= A_PTX_O2(P,T,X)	Thermal diffusivity	m^2/s
$\alpha_P = f(p,t,x)$	alphap_ptx_O2	= ALPHAP_PTX_O2(P,T,X)	Relative pressure coefficient	1/K
$\alpha_v = f(p,t,x)$	alphav_ptx_O2	= ALPHAV_PTX_O2(P,T,X)	Isobaric cubic expansion coefficient	1/K
$\beta_P = f(p,t,x)$	betap_ptx_O2	= BETAP_PTX_O2(P,T,X)	Isothermal stress coefficient	kg/m^3
$c_p = f(p,t,x)$	cp_ptx_O2	= CP_PTX_O2(P,T,X)	Specific isobaric heat capacity	kJ/(kg · K)
$c_v = f(p,t,x)$	cv_ptx_O2	= CV_PTX_O2(P,T,X)	Specific isochoric heat capacity	kJ/(kg · K)
$\eta = f(p,t,x)$	eta_ptx_O2	= ETA_PTX_O2(P,T,X)	Dynamic viscosity	Pa · s = kg/(m · s)
$h = f(p,t,x)$	h_ptx_O2	= H_PTX_O2(P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p,t,x)$	kappa_ptx_O2	= KAPPA_PTX_O2(P,T,X)	Isentropic exponent	-
$\kappa_T = f(p,t,x)$	kappat_ptx_O2	= KAPPAT_PTX_O2(P,T,X)	Isothermal compressibility	1/kPa
$\lambda = f(p,t,x)$	lambda_ptx_O2	= LAM_PTX_O2(P,T,X)	Thermal conductivity	W/(m · K)
$\nu = f(p,t,x)$	ny_ptx_O2	= NY_PTX_O2(P,T,X)	Kinematic viscosity	m^2/s
$p_{mel} = f(t)$	p_mel_t_O2	= P_MEL_T_O2(T)	Melting pressure	bar
$Pr = f(p,t,x)$	Pr_ptx_O2	= PR_PTX_O2(P,T,X)	Prandtl number	-
$p_S = f(t)$	ps_t_O2	= PS_T_O2(T)	Vapor pressure	bar
$\rho = f(p,t,x)$	rho_ptx_O2	= RHO_PTX_O2(P,T,X)	Density	kg / m^3
$s = f(p,t,x)$	s_ptx_O2	= S_PTX_O2(P,T,X)	Specific entropy	kJ/(kg · K)
$t_{mel} = f(p)$	t_mel_p_O2	= T_MEL_P_O2(P)	Melting temperature	°C

Functional Dependence	Function Name	Call from DLL LibO2, Result as Parameter	Property or Function	Unit of the Result
$t = f(p,h)$	t_ph_O2	= T_PH_O2(P,H)	Backward function: Temperature from pressure and enthalpy	°C
$t_s = f(p)$	ts_p_O2	= TSP_O2(P)	Saturation temperature	°C
$t = f(p,s)$	t_ps_O2	= T_PS_O2(P,S)	Backward function: Temperature from pressure and entropy	°C
$u = f(p,t,x)$	u_ptx_O2	= U_PTX_O2(P,T,X)	Specific internal energy	kJ/kg
$v = f(p,t,x)$	v_ptx_O2	= V_PTX_O2(P,T,X)	Specific volume	m^3/kg
$w = f(p,t,x)$	w_ptx_O2	= W_PTX_O2(P,T,X)	Speed of sound	m/s
$x = f(p,h)$	x_ph_O2	= X_PH_O2(P,H)	Backward function: Vapor fraction from pressure and enthalpy	kg/kg
$x = f(p,s)$	x_ps_O2	= X_PS_O2(P,S)	Backward function: Vapor fraction from pressure and entropy	kg/kg
$z = f(p,t,x)$	z_ptx_O2	= Z_PTX_O2(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 LibO2

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 the LibO2: t_t = 54.361K (-218.789°C) ... p_t = 1.46E-03 bar (t – triple point)
t_c = 154.581 K (-118.569°C) ... p_c = 50.43 bar (c – critical point)

Note.

If the calculation results in –1000, the values entered represent a state point beyond the range of validity.

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 LibO2 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_LibO2_x64_Eng.zip (for 64 bit version)

or

CD_FluidEXL_Graphics_LibO2_Eng.zip" (for 32 bit version).

you will see the folder

\CD_FluidEXL_Graphics_LibO2_x64_Eng\ (for 64 bit version)

or

\CD_FluidEXL_Graphics_LibO2_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_LibO2_Docu_Eng
LC.dll
LibO2.dll
LibO2.chm
Reg_.reg

Now, please copy the following folders and files

\FLUFT\
\Formulation97\
FluidEXL_Graphics_Eng.xla
LibO2.dll
LibO2.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)

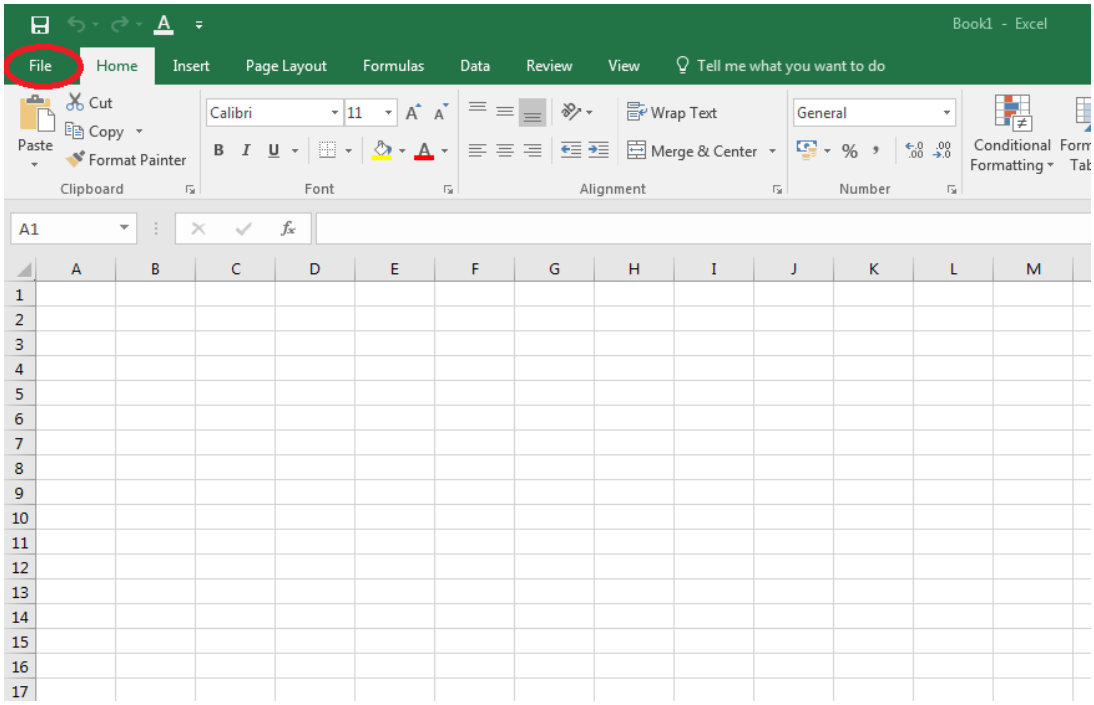

Figure 2.1: Registering FluidEXL*Graphics* as Add-In in Excel® 2016

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

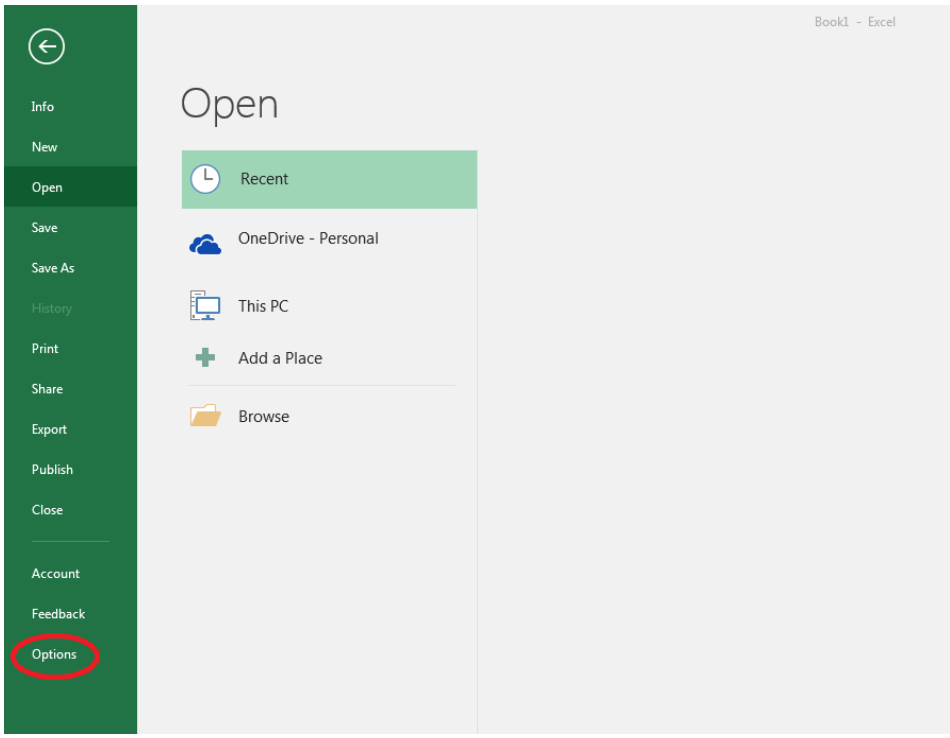

Figure 2.2: Registering FluidEXL*Graphics* as Add-In in Excel® 2016

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

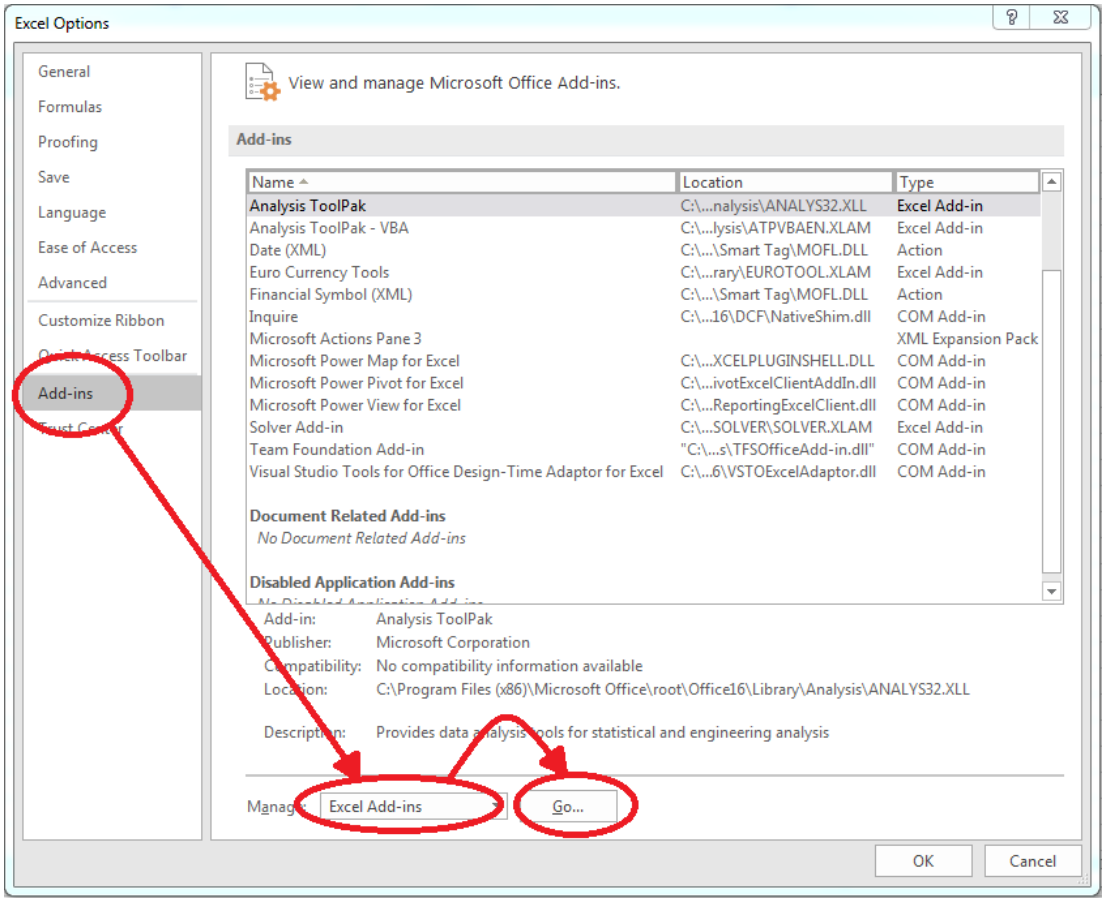

Figure 2.3: Dialog window "Excel Options"

- 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)

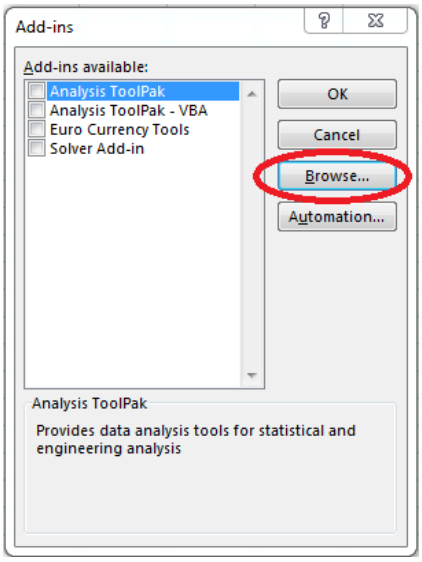

Figure 2.4: Dialog window "Add-ins"

- 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.

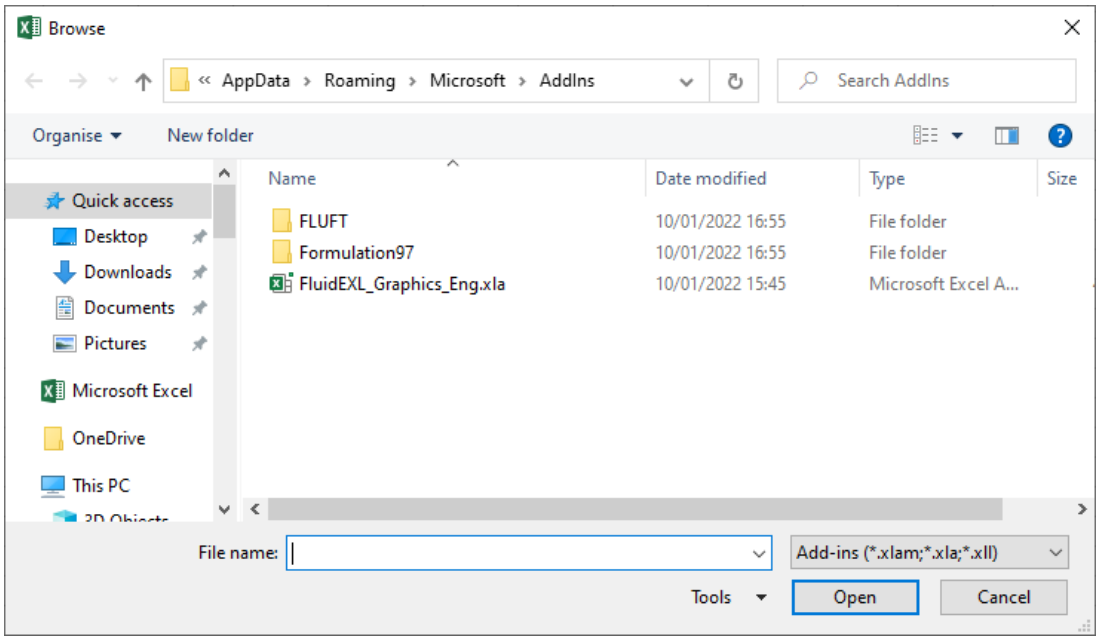

Figure 2.5: "Browse"-Window

  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
  LibO2.dll
  LibO2.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).

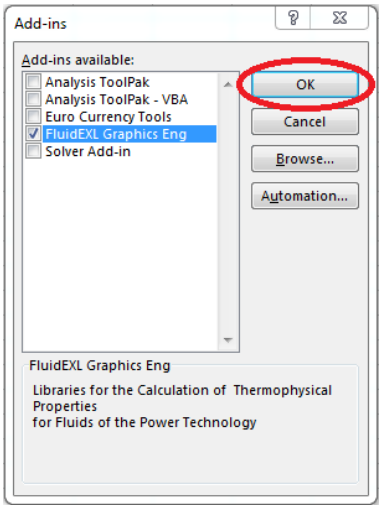

Figure 2.6: Dialog window "Add-Ins"

In order to use FluidEXL*Graphics* in the following example, click on the menu item "Add-Ins" shown in Fig. 2.7.

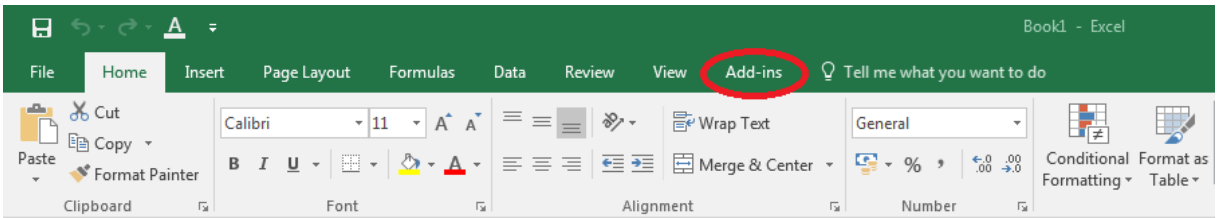

Figure 2.7: Menu item "Add-Ins"

In the upper menu region of Excel®, the FluidEXL*Graphics* menu bar will appear as marked with the red circle in Fig. 2.8.

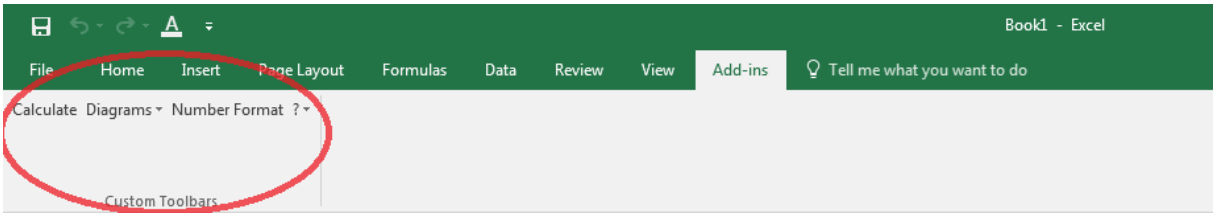

Figure 2.8: FluidEXL*Graphics* menu bar

The Installation of FluidEXL*Graphics* in Excel® is now complete.

An example calculation of "LibO2" DLL library property functions can be found in chapter 2.4.

2.3 Licensing the LibO2 Property LibO2rary

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).

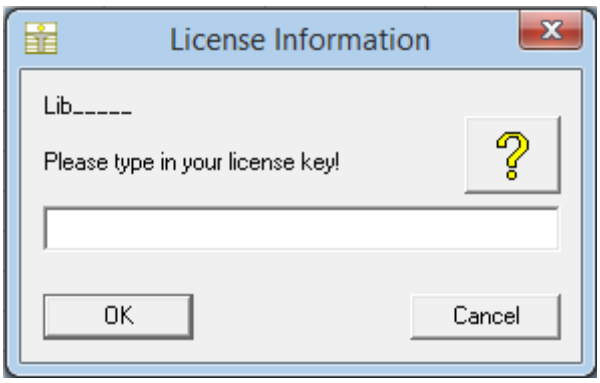

Figure 2.12: "License Information" window

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:

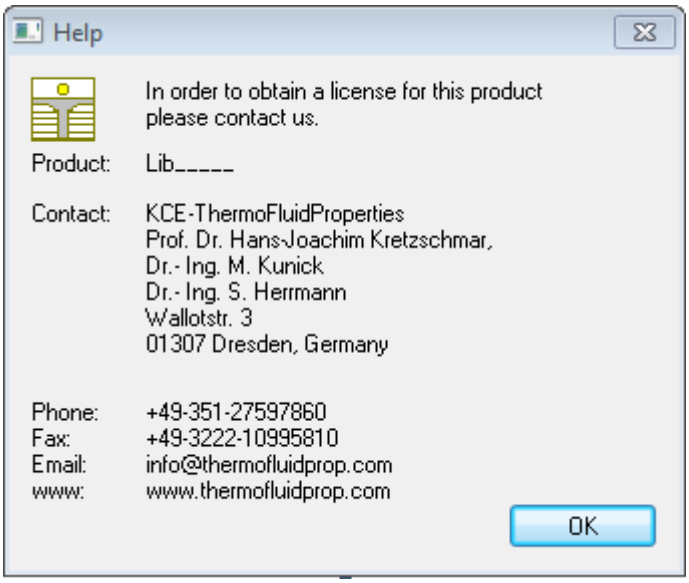

Figure 2.13: "Help" window

If you do not enter a valid license it is still possible to start Excel® by clicking "Cancel" twice. In this case, the LibO2 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 LibO2 property library, you have to delete the files

LibO2.dll
LibO2.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 "LibO2_ _ _ _ _ in Figure 2.12 and 2.13 stands for the LibO2rary you are installing. In this case it is the LibO2 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

  ⇒ e. g.: Enter the value -30 into cell A2

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

  ⇒ 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 = –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.

  ⇒ e.g.: Enter –1 into the C2 cell.

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

  ⇒ e.g.: Click the D2 cell.

- Click "Calculate" in the menu bar of FluidEXL*Graphics*.
  Now the "Insert Function" window appears (see next figure).

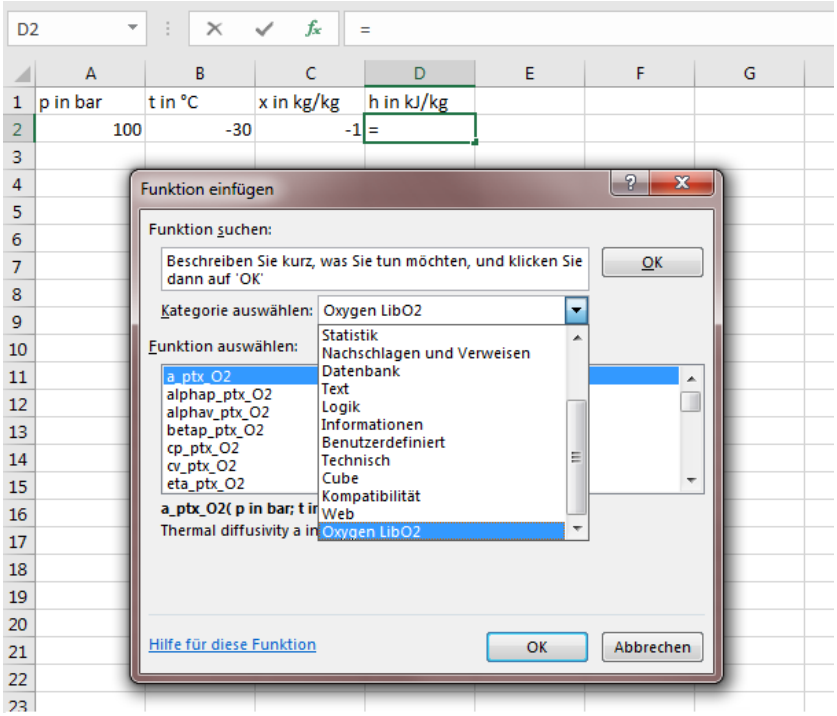

Figure 2.14: Choice of library and function name

- Search and click the "LibO2" library under "Or select a category:" in the upper part of the window.
- Search and click the h_ptx_O2 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.

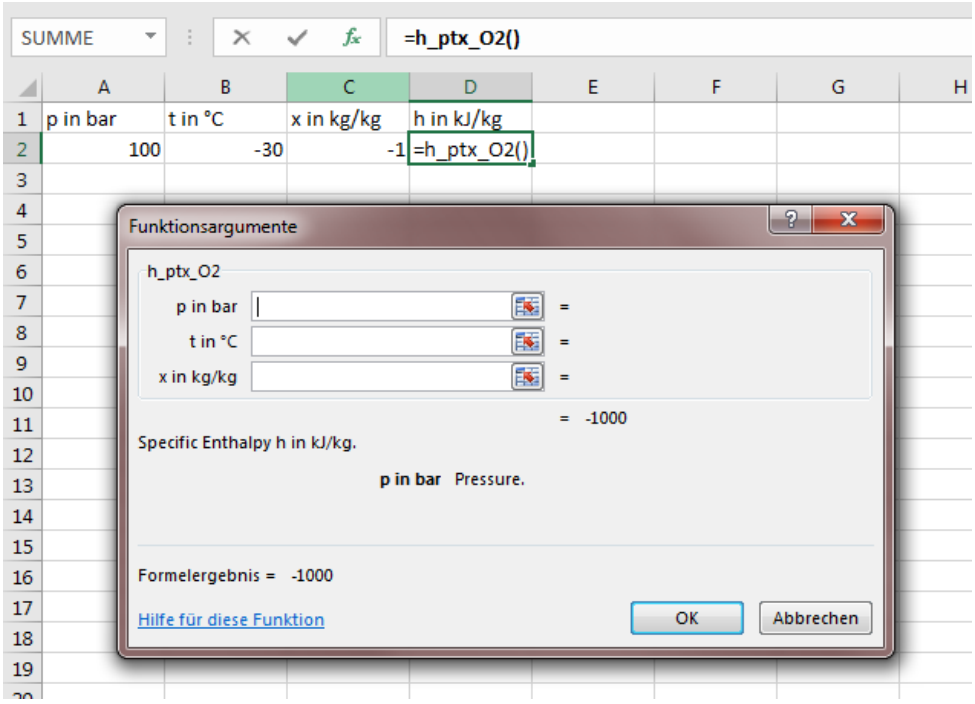

Figure 2.15: Input menu for the function

- 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:

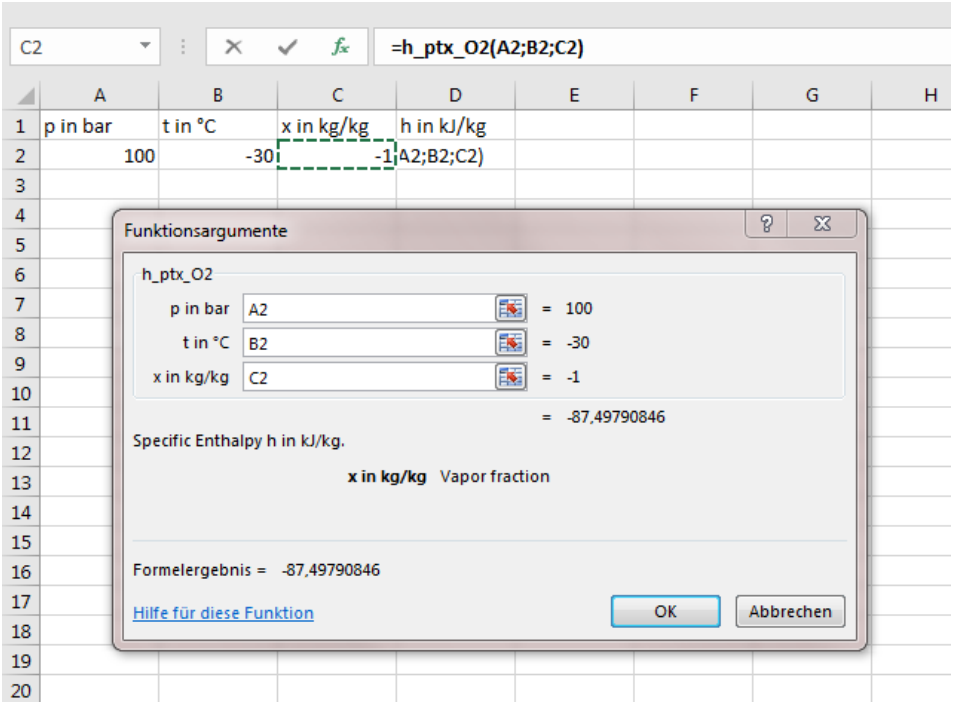

Figure 2.16: Input menu showing the result

- 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 = -87.49790846 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 "LibO2" library under "Or select a category:" will be marked automatically.

- Search for and click on the s_ptx_O2 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".

Note:

If the calculation results in –1, this indicates that the entered values are located outside the range of validity. More detailed information on each function and its range of validity is available in chapter 3.

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

Number Formats

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

- Click the cell or select and click on the cells you wish to format.
  (In empty cells the new format will be applied once a value has been entered.)
- Click "Number Format" in the FluidEXL*Graphics* menu bar.
- Select the desired number format in the dialog box which appears:

"STD – Standard":	Insignificant zeros behind the decimal point are not shown.
"FIX – Fixed Number of Digits":	All set decimal places are shown, including insignificant zeros.
"SCI – Scientific Format":	Numbers are always shown in the exponential form with the set number of decimal places.

- Set the "Number of decimal places" by entering the number into the appropriate window.
- Confirm this by clicking the "OK" button.

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

STD	1.23
FIX	1.230
SCI	1.230E+00

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

2.5 The FluidEXL*Graphics* Help System

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

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

- Click "Calculate" in the FluidEXL*Graphics* menu bar.
- Click on the “LibO2” 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.

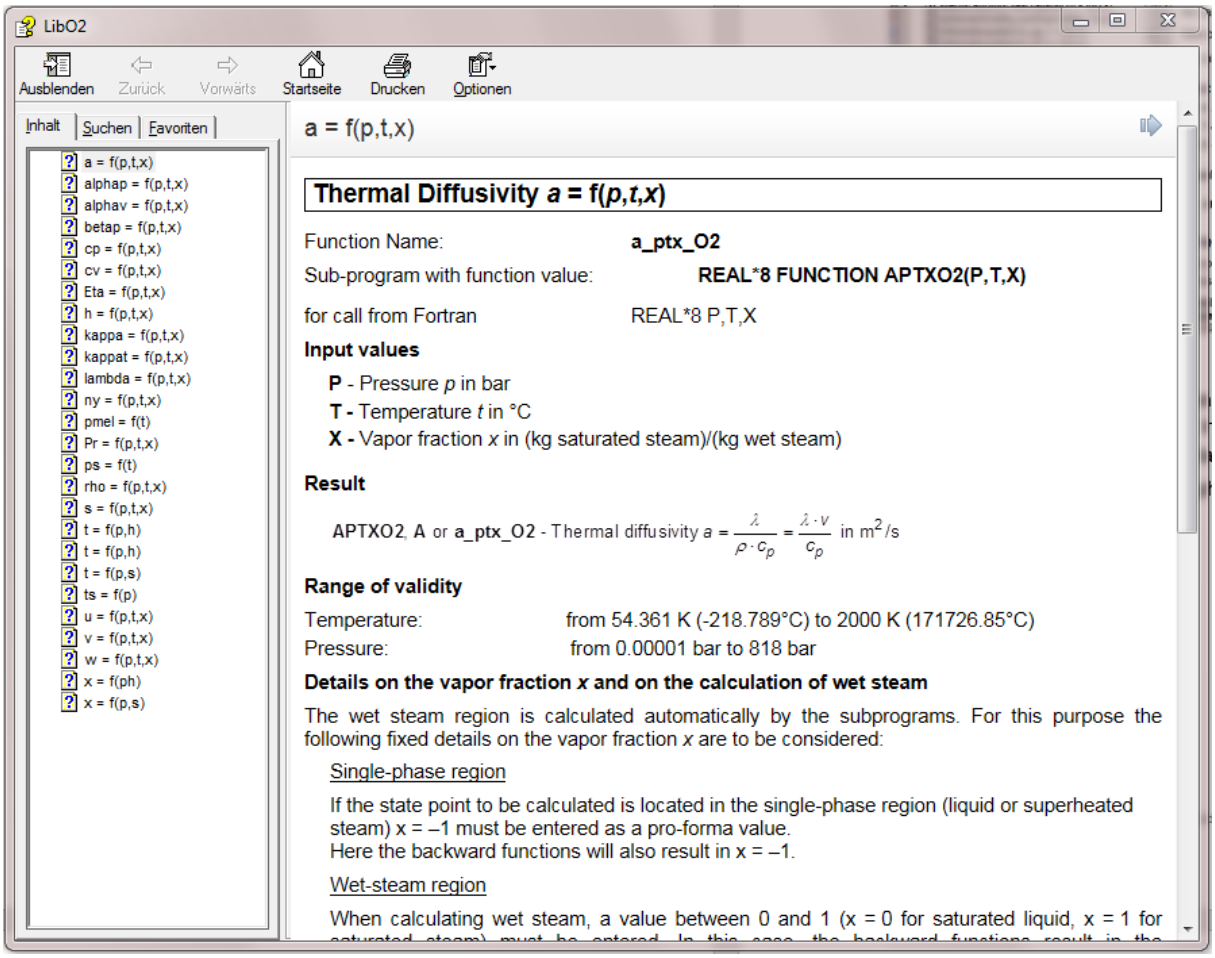

Figure 2.17: Help Window

If the LibO2.chm function help cannot be found, you will be redirected to a Microsoft® help website by your standard browser. In this case, the LibO2.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 LibO2 Library

Should you wish to remove <u>only</u> the LibO2 library, delete the files

LibO2.dll
LibO2.chm

in the directory selected for the installation of FluidEXL*Graphics*, in the standard case,

C:\Program Files\FluidEXL_Graphics_Eng

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

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

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

- Click the “File” button in the upper left corner of Excel®
- Click on the "Options" button in the menu which appears

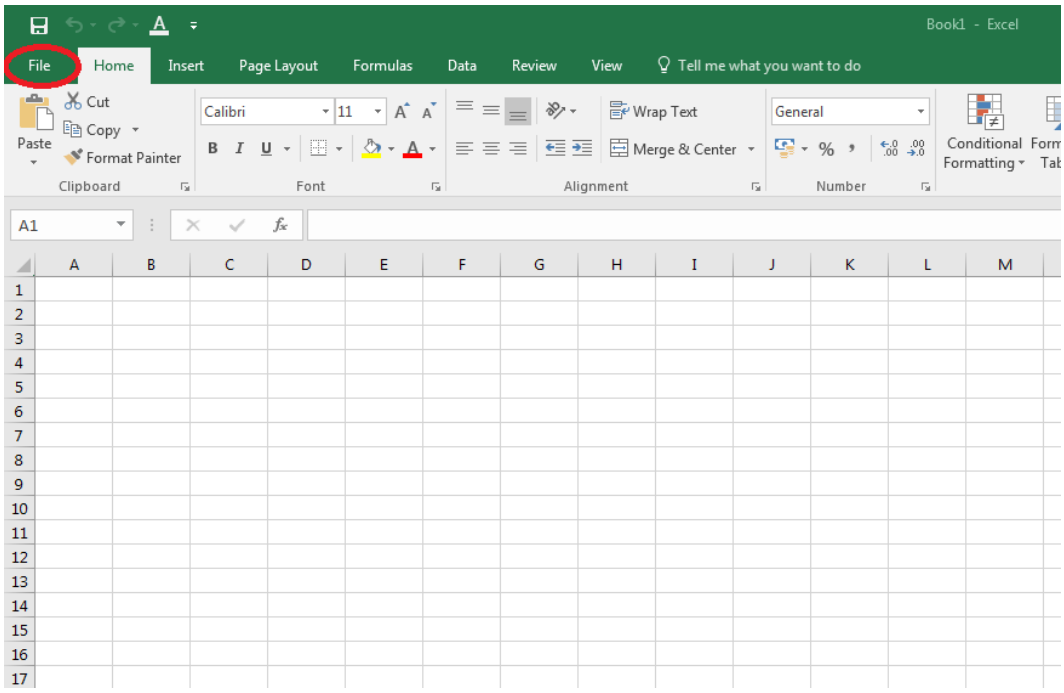

Figure 2.18: Unregistering FluidEXL*Graphics* as Add-In in Excel® 2016

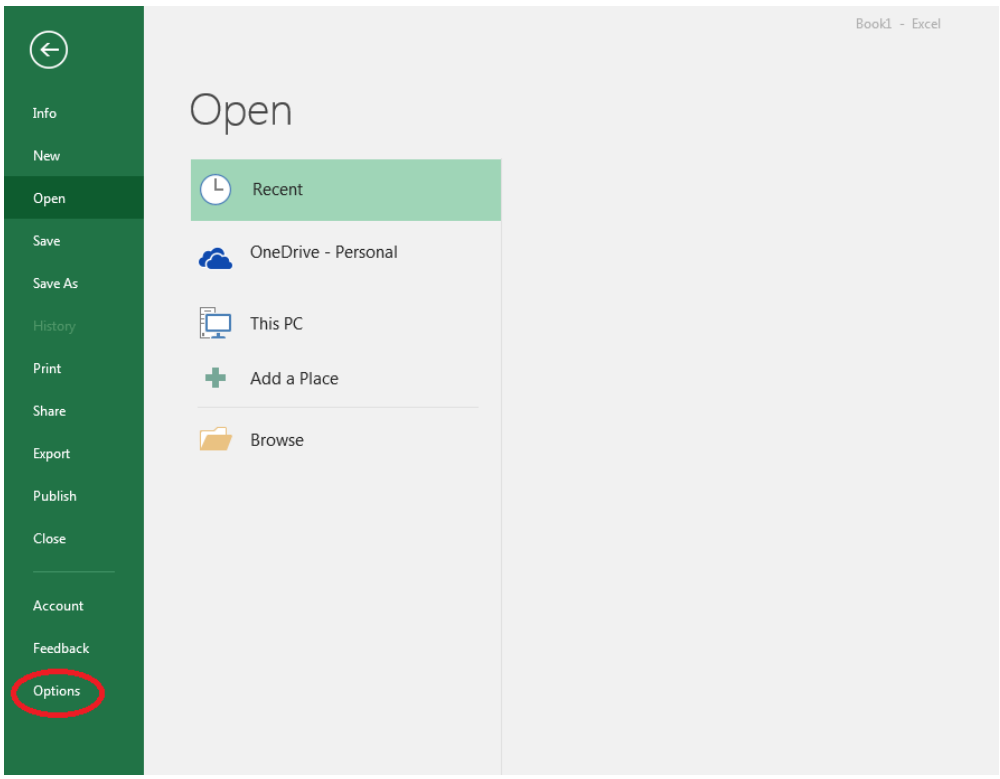

Figure 2.19 Unregistering FluidEXL*Graphics* as Add-In in Excel® 2016

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

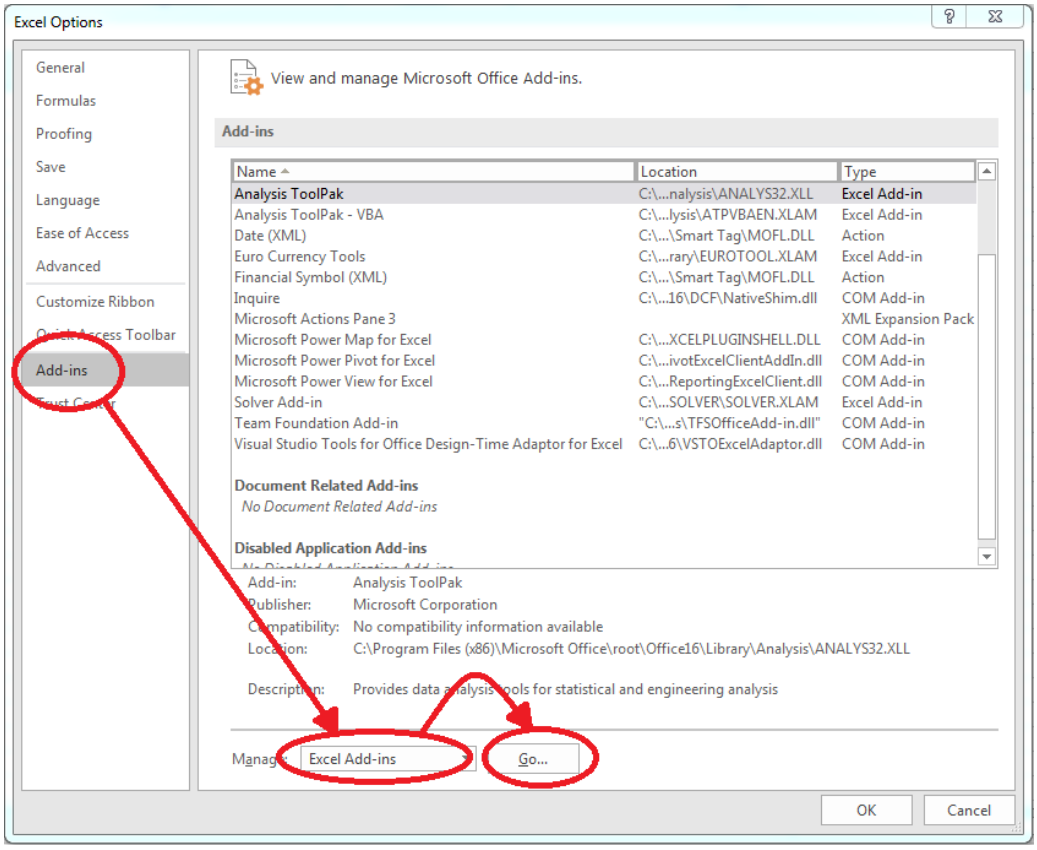

Figure 2.20: Dialog window "Add-Ins"

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

- Afterwards click the "Go…" button
- Remove the checkmark in front of

  "FluidEXL Graphics Eng"

  in the window which now appears. Click the "OK" button to confirm your entry.

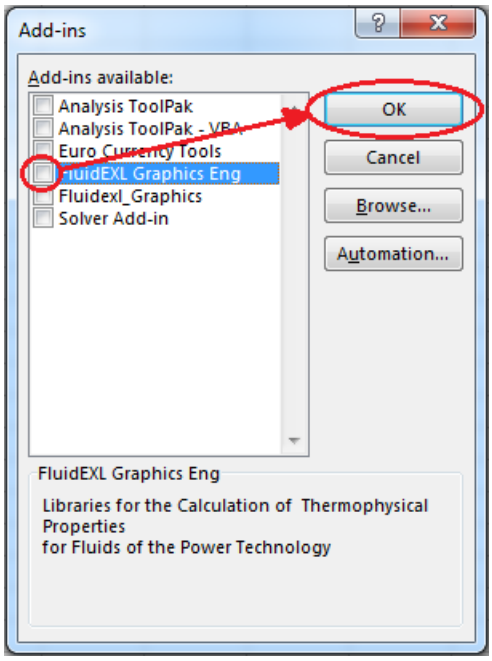

Figure 2.21: Dialog window "Add-Ins"

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

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

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

"FluidEXL Graphics Eng"

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

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

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

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

Now FluidEXL*Graphics* has been completely removed from your computer.

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

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

FluidEXL_Graphics_Eng.xla

has to be cancelled in Excel®.

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

"FluidEXL Graphics Eng"

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

recommend closing Excel®.

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

"FluidEXL Graphics Eng"

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

Within the next step delete the files

LibO2.dll
LibO2.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_O2**

Sub-program with function value: **REAL*8 FUNCTION APTXO2(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

APTXO2, **A** or **a_ptx_O2** - Thermal diffusivity $a = \frac{\lambda}{\rho \cdot c_p} = \frac{\lambda \cdot v}{c_p}$ in m^2/s

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **APTXO2, A = –1** or **a_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 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_O2**

Sub-program with function value: **REAL*8 FUNCTION ALPHAPPTXO2(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

ALPHAPPTXO2, **ALPHAP** or **alphap_ptx_O2** - Relative pressure coefficient α_p in 1/K

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **ALPHAPPTXO2, ALPHAP = –1000** or **alphap_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 bar or p > 0.00001 bar
and $|t-t_s(p)|$ > 0.1 K

References: [1], [2]

Isobaric Cubic Expansion Coefficient α_v = f(*p*,*t*,*x*)

Function Name: **ALPHAV_ptx_O2**

Sub-program with function value: **REAL*8 FUNCTION ALPHAVPTXO2(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

ALPHAVPTXO2, **ALPHAV** or **alphav_ptx_O2** - Isobaric cubic expansion coefficient α_v in 1/K

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **ALPHAVPTXO2, ALPHAV = –1000** or **alphav_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 bar or p > 0.00001 bar
and $|t-t_s(p)|$ > 0.1 K

References: [1], [2]

Isothermal Stress Coefficient β_p = f(p,t,x)

Function Name: **BETAP_ptx_O2**

Sub-program with function value: **REAL*8 FUNCTION BETAPPTXO2(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

BETAPPTXO2, **BETAP** or **betap_ptx_O2** - Isothermal stress coefficient β_p in kg / m^3

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **BETAPPTXO2, BETAP = –1000** or **betap_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 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_O2**

Sub-program with function value: **REAL*8 FUNCTION CPPTXO2(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

CPPTXO2, **CP** or **cp_ptx_O2** - Specific isobaric heat capacity c_p in kJ/kg K

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **CPPTXO2, CP = –1000** or **cp_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 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_O2**

Sub-program with function value: **REAL*8 FUNCTION CVPTXO2 (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

CVPTXO2, **CV** or **cv_ptx_O2** - Specific isochoric heat capacity c_v in kJ/kg K

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **CVPTXO2, CV = –1000** or **cv_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 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_O2**

Sub-program with function value: **REAL*8 FUNCTION ETAPTXO2(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

ETAPTXO2, **ETA** or **eta_ptx_O2** - Dynamic viscosity η in Pa s

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **ETAPTXO2, ETA = –1000** or **eta_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 bar or p > 0.00001 bar
and $|t-t_s(p)|$ > 0.1 K

References: [2]

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

Function Name:	**h_ptx_O2**
Sub-program with function value:	**REAL*8 FUNCTION HPTXO2(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

HPTXO2, H or **h_ptx_O2** - Specific enthalpy *h* in kJ/kg

Range of validity

Temperature:	from 54.361 K (-218.789°C) to 2000 K (1726.85°C)
Pressure:	from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **HPTXO2, H = –1000** or **h_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)	p > 818 bar or p < 0.00001 bar or t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$
Saturation lines: (x = 0 or x = 1)	at p = –1000 and t > -118.569 °C or t < -218.789 °C at t = –1000 and p > 50.43 bar or p < 0.00001 bar or at p < 50.43 bar or p > 0.00001 bar and $\lvert t-t_s(p)\rvert$ > 0.1 K

References: [2]

Isentropic Exponent κ = f(p,t,x)

Function Name: **Kappa_ptx_O2**

Sub-program with function value: **REAL*8 FUNCTION KAPPAPTXO2(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

KAPPAPTXO2, **KAPPA** or **kappa_ptx_O2** - Isentropic exponent $\kappa = -\frac{v}{p}\left(\frac{\partial p}{\partial v}\right)_s = \frac{w^2}{p \cdot v}$

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **KAPPAPTXO2, KAPPA = –1000** or **kappa_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 bar or p > 0.00001 bar
and $|t-t_s(p)|$ > 0.1 K

References: [1], [2]

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

Function Name: **kappat_ptx_O2**

Sub-program with function value: **REAL*8 FUNCTION KAPPATPTXO2(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

KAPPATPTXO2, **KAPPAT** or **kappat_ptx_O2** - Isothermal compressibility κ_T in 1/kPa

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **KAPPATPTXO2, KAPPAT = –1000** or **kappat_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 bar or p > 0.00001 bar
and $|t-t_s(p)|$ > 0.1 K

References: [1], [2]

Thermal Conductivity λ = f(p,t,x)

Function Name: **Lambda_ptx_O2**

Sub-program with function value: **REAL*8 FUNCTION LAMPTXO2(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

LAMPTXO2, **LAMBDA** or **lambda_ptx_O2** - Thermal conductivity λ in W/m·K

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **LAMPTXO2, LAMBDA = –1000** or **Lambda_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 bar or p > 0.00001 bar
and $|t-t_s(p)|$ > 0.1 K

References: [1], [2]

Kinematic Viscosity ν = f(p,t,x)

Function Name: **Ny_ptx_O2**

Sub-program with function value: **REAL*8 FUNCTION NYPTXO2(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

NYPTXO2, **NY** or **ny_ptx_O2** - Kinematic viscosity $\nu = \frac{\eta}{\rho} = \eta \cdot v$ in m^2 / s

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **NYPTXO2, NY = –1000** or **Ny_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 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_O2**

Sub-program with function value: **REAL*8 FUNCTION PMELTO2(T)**
for call from Fortran REAL*8 PMELT,T

Input values

T - temperature t in °C

Result

PMELTO2, **P** or **pmel_t_O2** – Melting pressure p_{mel} in bar

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Results for wrong input values

Result **PMELTO2, P = –1000** or **pmel_t_O2 = –1000** for input values:
p < 0.00001 bar or p > 818 bar

References: [1], [2]

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

Function Name: **Pr_ptx_O2**

Sub-program with function value: **REAL*8 FUNCTION PRPTXO2(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

PRPTXO2, **Pr** or **Pr_ptx_O2** - Prandtl number $Pr = \frac{\nu}{a} = \frac{\eta \cdot c_p}{\lambda}$

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **PRPTXO2, PR = –1000** or **Pr_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 bar or p > 0.00001 bar
and $|t-t_s(p)|$ > 0.1 K

References: [1], [2]

Vapor Pressure p_s = f(t)

Function Name:	**ps_t_O2**
Sub-program with function value:	**REAL*8 FUNCTION PSTO2(T)**
for call from Fortran	REAL*8 T

Input values

T - Temperature t in °C

Result

PSTO2, **PS** or **ps_t_O2** – Vapor pressure p_s in bar

Range of validity

from t_t = -218.789 °C to t_c = -118.569 °C

Results for wrong input values

Result **PSTO2, PS = –1000** or **ps_t_O2 = –1000** for input values:
t < -218.789 °C or t > -118.569 °C

References: [2]

Density ρ = f(p,t,x)

Function Name: **Rho_ptx_O2**

Sub-program with function value: **REAL*8 FUNCTION RHOPTXO2(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

RHOPTXO2, **RHO** or **rho_ptx_O2** - Density $\rho = \frac{1}{v}$ in kg / m^3

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **RHOPTXO2, RHO = –1000** or **rho_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 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_O2**

Sub-program with function value: **REAL*8 FUNCTION SPTXO2(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

SPTXO2, S or **s_ptx_O2** - Specific entropy *s* in kJ/kg K

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **SPTXO2, S = –1000** or **s_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 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_O2**
Sub-program with function value:	**REAL*8 FUNCTION TPHO2(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

TPHO2, T or **t_ph_O2** - Temperature *t* in °C

Range of validity

Temperature:	from 54.361 K (-218.789°C) to 2000 K (1726.85°C)
Pressure:	from 0.00001 bar to 818 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 **TPHO2, T = –1000** or **t_ph_O2 = –1000** for input values:

Single phase region:	$p > 818$ bar or $p < 0.00001$ bar or
($x = -1$)	$t > 1726.85$°C or $t < -118.569$ °C or $t < t_{mel}(p)$
Saturation lines:	at p = –1000 and $t > -118.569$ °C or $t < -218.789$ °C
($x = 0$ or $x = 1$)	at t = –1000 and p > 50.43 bar or $p < 0.00001$ bar or
	at $p < 50.43$ bar or $p > 0.00001$ bar
	and $\lvert t - t_s(p) \rvert > 0.1$ K

References: [2]

Melting Temperature t_{mel} = f(p)

Function Name:	**tmel_p_O2**
Sub-program with function value:	**REAL*8 FUNCTION TMELPO2(P)**
for call from Fortran	REAL*8 TMELP,P

Input values

P - Pressure p in bar

Result

TMELPO2, **T** or **tmel_p_O2** – Melting temperature t_{mel} in °C

Range of validity

Pressure: from 0.00001 bar to 818 bar

Results for wrong input values

Result **TMELPO2, T = –1000** or **tmel_p_O2 = –1000** for input values:

$p < 0.00001$ bar or $p > 818$ bar

References: [1], [2]

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

Function Name:	**t_ps_O2**
Sub-program with function value:	**REAL*8 FUNCTION TPSO2(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

TPSO2, T or **t_ps_O2** - Temperature *t* in °C

Range of validity

Temperature:	from 54.361 K (-218.789°C) to 2000 K (1726.85°C)
Pressure:	from 0.00001 bar to 818 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 **TPSO2, T = –1000** or **t_ps_O2 = –1000** for input values:

Single phase region:	$p > 818$ bar or $p < 0.00001$ bar or
($x = -1$)	$t > 1726.85$°C or $t < -118.569$ °C or $t < t_{mel}(p)$
Saturation lines:	at p = –1000 and $t > -118.569$ °C or $t < -218.789$ °C
($x = 0$ or $x = 1$)	at t = –1000 and p > 50.43 bar or $p < 0.00001$ bar or
	at $p < 50.43$ bar or $p > 0.00001$ bar
	and $\lvert t-t_s(p)\rvert > 0.1$ K

References: [2]

Saturation Temperature t_S = f(p)

Function Name:	**ts_p_O2**
Sub-program with function value:	**REAL*8 FUNCTION TSPO2(P)**
for call from Fortran	REAL*8 P

Input values

P - Pressure p in bar

Result

TSPO2, **T** or **ts_p_O2** - Saturation temperature t_S in °C

Range of validity

from p_t = 0.00001 bar to p_c = 50.43 bar

Results for wrong input values

Result **TSPO2, T = –1000** or **ts_p_O2 = –1000** for input values:
p < 0.00001 bar or p > 50.43 bar

References: [2]

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

Function Name: **u_ptx_O2**

Sub-program with function value: **REAL*8 FUNCTION UPTXO2(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

UPTXO2, U or **u_ptx_O2** - Specific internal energy *u* in kJ/kg

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **UPTXO2, U = –1000** or **u_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 bar or p > 0.00001 bar
and $|t-t_s(p)|$ > 0.1 K

References: [1], [2]

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

Function Name: **v_ptx_O2**

Sub-program with function value: **REAL*8 FUNCTION VPTXO2(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

VPTXO2, **V** or **v_ptx_O2** - Specific volume *v* in m^3/kg

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **VPTXO2, V = –1000** or **v_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 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_O2**

Sub-program with function value: **REAL*8 FUNCTION WPTXO2(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

WPTXO2, W or **w_ptx_O2** - Isentropic speed of sound *w* in m/s

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **WPTXO2, W = –1000** or **w_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 bar or p > 0.00001 bar
and $|t-t_s(p)|$ > 0.1 K

References: [1], [2]

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

Function Name:	**x_ph_O2**
Sub-program with function value:	**REAL*8 FUNCTION XPHO2(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

XPHO2, X or **x_ph_O2** - Vapor fraction *x* in (kg saturated steam)/(kg wet steam)

Range of validity

Temperature:	from 54.361 K (-218.789°C) to 2000 K (1726.85°C)
Pressure:	from 0.00001 bar to 818 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 **XPHO2, X = –1** or **x_ph_O2 = –1** for input values:

if the state point is located in the single phase region

$p > 50.43$ bar or $p < 0.00001$ bar

References: [1], [2]

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

Function Name:	**x_ps_O2**
Sub-program with function value:	**REAL*8 FUNCTION XPSO2(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

XPSO2, X or **x_ps_O2** - Vapor fraction *x* in (kg saturated steam)/(kg wet steam)

Range of validity

Temperature:	from 54.361 K (-218.789°C) to 2000 K (1726.85°C)
Pressure:	from 0.00001 bar to 818 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 **XPSO2, X = –1** or **x_ps_O2 = –1** for input values:

if the state point is located in the single phase region

$p > 50.43$ bar or $p < 0.00001$ bar

References: [1], [2]

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

Function Name: **z_ptx_O2**

Sub-program with function value: **REAL*8 FUNCTION ZPTXO2(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

ZPTXO2, Z or **z_ptx_O2** - Isentropic speed of sound *w* in m/s

Range of validity

Temperature: from 54.361 K (-218.789°C) to 2000 K (1726.85°C)

Pressure: from 0.00001 bar to 818 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 LibO2: t_t = -218.789 °C ... p_t = 0.12523 bar (t – triple point)
t_c = -118.569 °C ... p_c = 50.43 bar (c – critical point)

Results for wrong input values

Result **ZPTXO2, Z = –1000** or **z_ptx_O2 = –1000** for input values:

Single phase region: (x = –1)
p > 818 bar or p < 0.00001 bar or
t > 1726.85°C or t < -118.569 °C or $t < t_{mel}(p)$

Saturation lines: (x = 0 or x = 1)
at p = –1000 and t > -118.569 °C or t < -218.789 °C
at t = –1000 and p > 50.43 bar or p < 0.00001 bar or
at p < 50.43 bar or p > 0.00001 bar
and $|t-t_s(p)|$ > 0.1 K

References: [1], [2]

KCE ThermoFluidProperties

KCE-ThermoFluidProperties
www.thermofluidprop.com

Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

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

Water and Steam

Library LibIF97

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

Library LibIF97_META

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

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:

CO_2 - Span, Wagner H_2O - IAPWS-95
O_2 - Schmidt, Wagner N_2 - Span et al.
Ar - Tegeler et al.

and of the ideal gases:
SO_2, CO, Ne
(Scientific Formulation of Bücker et al.)

Consideration of:

- Dissociation from VDI 4670
- Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:

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

Consideration of:

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

Extremely Fast Property Calculations

Spline-Based Table Look-up Method (SBTL)

Library LibSBTL_IF97
Library LibSBTL_95
Library LibSBTL_HuAir

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

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

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

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Humid Air

Library ASHRAE LibHuAirProp

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

Consideration of:

- Enhancement of the partial saturation pressure of water vapor at elevated total pressures

www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bücker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bücker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

IAPWS Guideline 2001 of Tillner-Roth and Friend (1998)

Helmholtz energy equation for the mixing term

(also useable for calculating the Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

$C_2H_6O_2$	Ethylene glycol
$C_3H_8O_2$	Propylene glycol
C_2H_5OH	Ethanol
CH_3OH	Methanol
$C_3H_8O_3$	Glycerol
K_2CO_3	Potassium carbonate
$CaCl_2$	Calcium chloride
$MgCl_2$	Magnesium chloride
NaCl	Sodium chloride
$C_2H_3KO_2$	Potassium acetate
$CHKO_2$	Potassium formate
LiCl	Lithium chloride
NH_3	Ammonia

Formulation of the International Institute of Refrigeration (IIR 2010)

Ethanol

Library LibC2H5OH

Formulation of
Schroeder et al. (2014)

Methanol

Library LibCH3OH

Formulation of
de Reuck and Craven (1993)

Propane

Library LibPropane

Formulation of
Lemmon et al. (2009)

Siloxanes as ORC Working Fluids

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

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

Tetradecamethylhexasiloxane $C_{14}H_{42}O_5Si_6$ **Library LibMD4M**

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Nitrogen and Oxygen

Libraries LibN2 and LibO2

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

Hydrogen

Library LibH2

Formulation of
Leachman et al. (2009)

Helium

Library LibHe

Formulation of
Arp et al. (1998)

Hydrocarbons

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

Isopentane C_5H_{12} **Library LibC5H12_Iso**

Neopentane C_5H_{12} **Library LibC5H12_Neo**

Isohexane C_6H_{14} **Library LibC6H14**

Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

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

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

Hydrogen sulfide H_2S **Library LibH2S**

Nitrous oxide N_2O **Library LibN2O**

Sulfur dioxide SO_2 **Library LibSO2**

Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

KCE ThermoFluidProperties

For more information please contact:

KCE-ThermoFluidProperties UG & Co. KG
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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 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

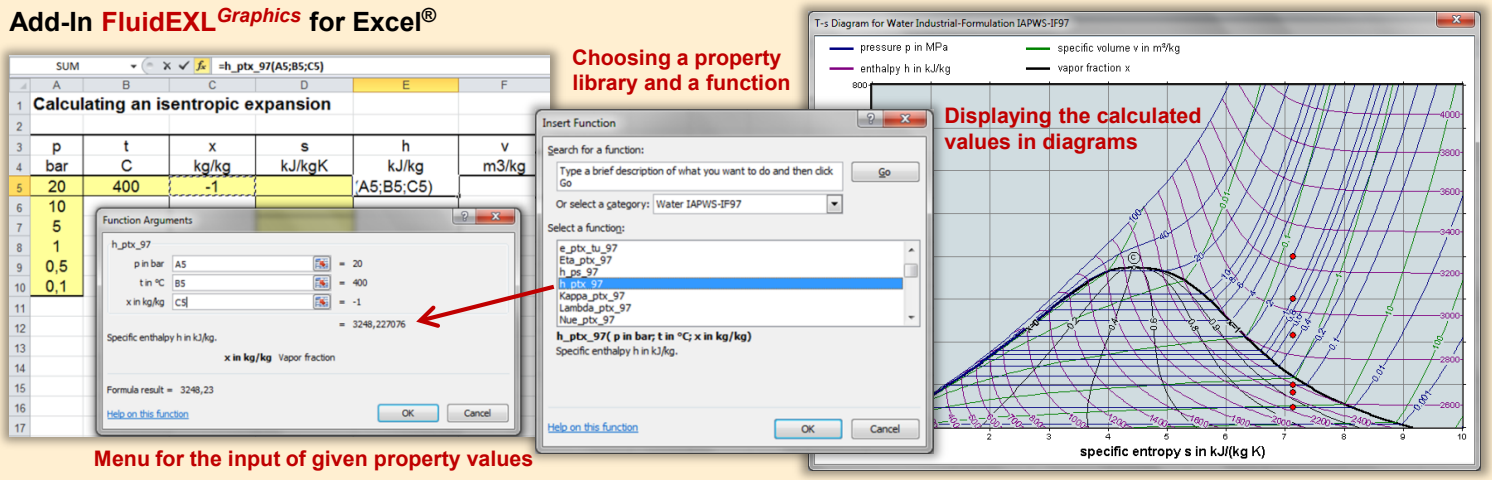
KCE-ThermoFluidProperties
www.thermofluidprop.com

KCE ThermoFluidProperties

Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

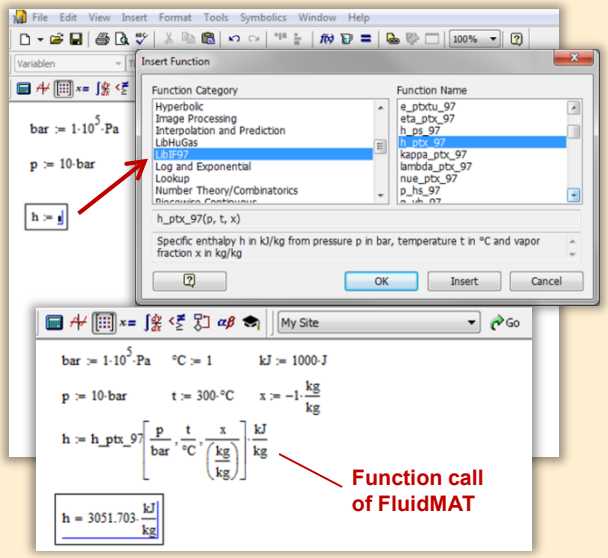
Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Add-In FluidEXL*Graphics* for Excel®



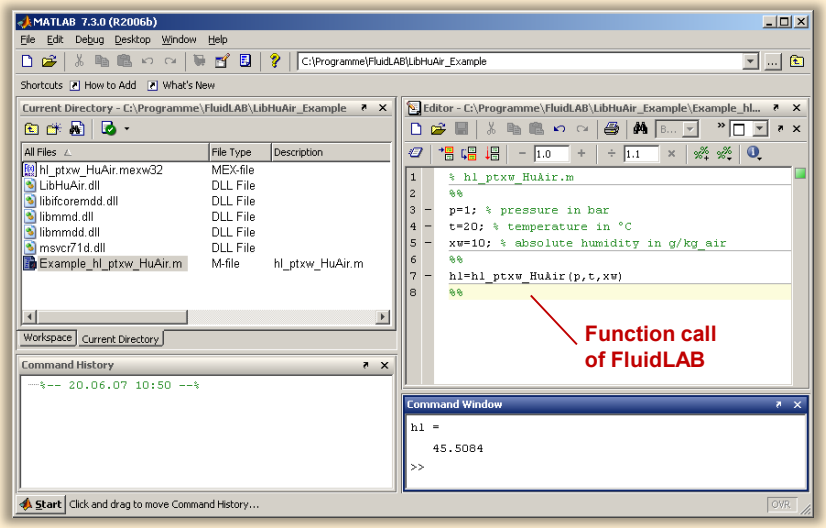
Add-On FluidMAT for Mathcad®
Add-On FluidPRIME for Mathcad Prime®

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



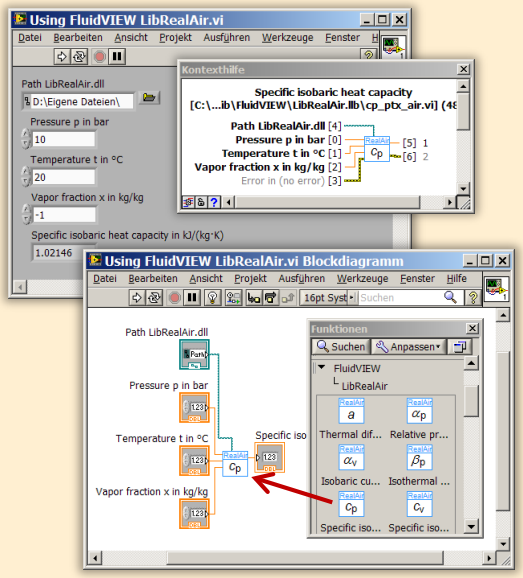
Add-On FluidLAB for MATLAB® and SIMULINK®

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



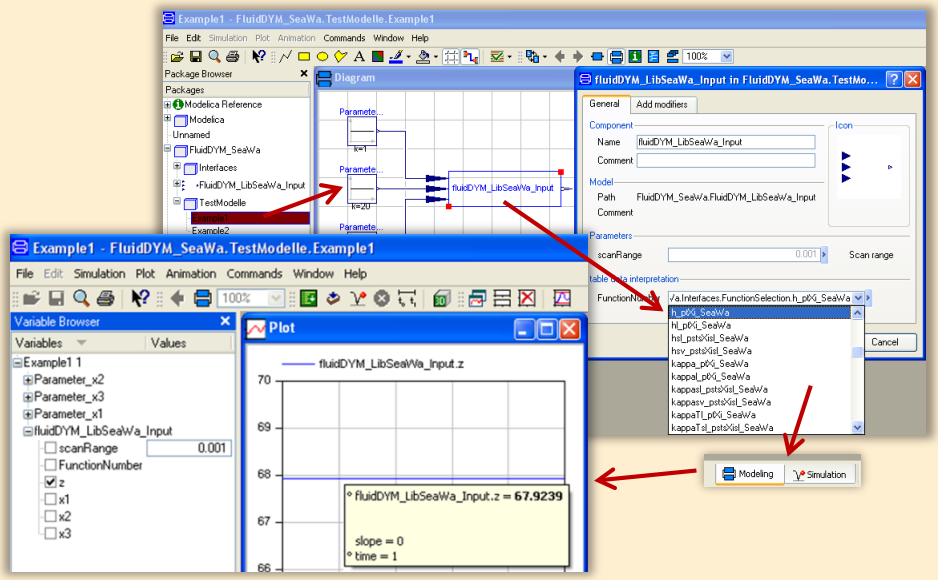
Add-On FluidVIEW for LabVIEW™

The property functions can be calculated in LabVIEW™.

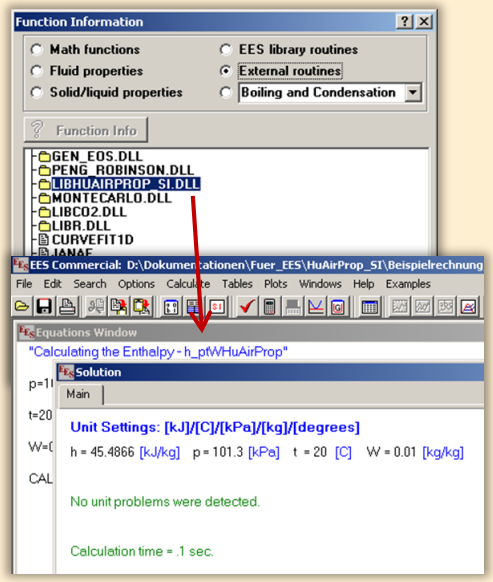


Add-On FluidDYM for DYMOLA® (Modelica) and SimulationX®

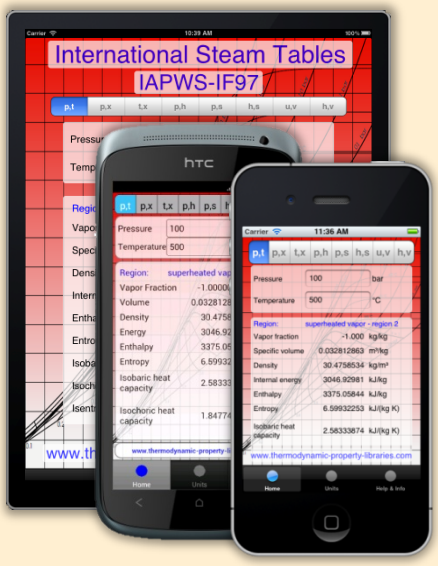
The property functions can be called in DYMOLA® and SimulationX®.



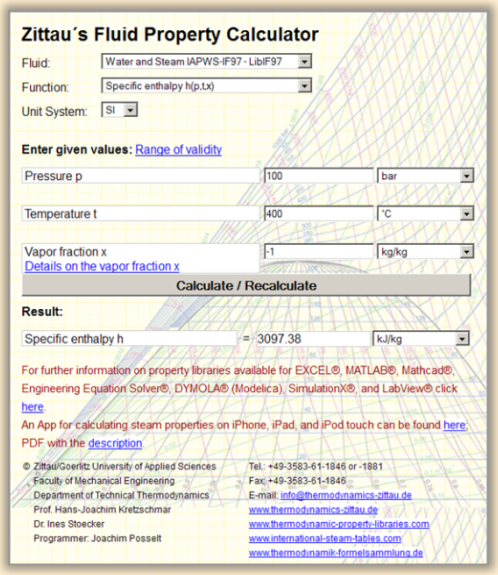
Add-On FluidEES for Engineering Equation Solver®



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



Online Property Calculator at www.thermofluidprop.com



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:

KCE ThermoFluidProperties

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Phone: +49-351-27597860
Mobile: +49-172-7914607
Fax: +49-3222-1095810

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

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

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] Schmidt, R; Wagner, W: A New Form of the Equation of State for Pure Substances and its Application to Oxygen Fluid, Phase Equilibria, 19:175-200, 1985

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