Property Library for Helium

FluidLAB
with LibHe
for MATLAB®

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Software for the Calculation of the Properties of Helium

FluidLAB

LibHe

Contents

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0. Package Contents

0.1 Zip file for 32-bit MATLAB®

The following zip file is delivered for your computer running a 32-bit version of MATLAB®.

"CD_FluidLAB_LibHe.zip"

Including the following files:

FluidLAB_LibHe_Setup.exe	- Installation program for the FluidLAB Add-On for use in MATLAB®
LibHe.dll	- Dynamic Link Library for helium for use in MATLAB®
FluidLAB_LibHe_Docu_Eng.pdf	- User's Guide

0.2 Zip file for 64-bit MATLAB®

The following zip file is delivered for your computer running a 64-bit version of MATLAB®.

"CD_FluidLAB_LibHe_x64.zip"

Including the following files and folders:

Files:

Setup.exe	- Self-extracting and self-installing program for FluidLAB
FluidLAB_LibHe_64.msi	- Installation program for the FluidLAB Add-On for use in MATLAB®
LibHe.dll	- Dynamic Link Library for helium for use in MATLAB®
FluidLAB_LibHe_Docu_Eng.pdf	- User's Guide

Folders:

vcredist_x64	- Folder containing the "Microsoft Visual C++ 2010 x64 Redistributable Pack"
WindowsInstaller3_1	- Folder containing the "Microsoft Windows Installer"

1. Property Functions

Functional Dependence	Function Name	Call from Fortran program	Call in DLL LibH2 as parameter	Property or Function	Unit of the result
$a = f(p,t,x)$	a_ptx_He	APTXHE(P,T,X)	C_APTXHE(A,P,T,X)	Thermal diffusivity	m^2/s
$c_p = f(p,t,x)$	cp_ptx_He	CPPTXHE(P,T,X)	C_CPPTXHE(CP,P,T,X)	Specific isobaric heat capacity	kJ/(kg K)
$c_v = f(p,t,x)$	cp_ptx_He	CVPTXHE(P,T,X)	C_CVPTXHE(CV,P,T,X)	Specific isochoric heat capacity	kJ/(kg K)
$\eta = f(p,t,x)$	eta_ptx_He	ETAPTXHE(P,T,X)	C_ETAPTXHE(ETA,P,T,X)	Dynamic viscosity	Pa s
$h = f(p,t,x)$	h_ptx_He	HPTXHE(P,T,X)	C_HPTXHE(H,P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p,t,x)$	kappa_ptx_He	KAPPTXHE(P,T,X)	C_KAPPTXHE(KAP,P,T,X)	Isentropic exponent	-
$\lambda = f(p,t,x)$	lambda_ptx_He	LAMPTXHE(P,T,X)	C_LAMPTXHE(LAM,P,T,X)	Thermal conductivity	W/(m K)
$\mu = f(p,t,x)$	mue_ptx_He	MUEPTXHE(P,T,X)	C_MUEPTXHE(MUE,P,T,X)	Joule-Thomson Coefficient	K/bar
$\nu = f(p,t,x)$	ny_ptx_He	NYPTXHE(P,T,X)	C_NYPTXHE(NY,P,T,X)	Kinematic viscosity	m^2/s
$p_{mel} = f(t)$	pmel_t_He	PMELTHE(T)	C_PMELTHE(PMEL,T)	Melting pressure from temperature	bar
$p_s = f(t)$	ps_t_He	PSTHE(T)	C_PSTHE(PS,T)	Vapor pressure from temperature	bar
$Pr = f(p,t,x)$	Pr_ptx_He	PRPTXHE(P,T,X)	C_PRPTXHE(PR,P,T,X)	*Prandtl*-Number	-
$\rho = f(p,t,x)$	rho_ptx_He	RHOPTXHE(P,T,X)	C_RHOPTXHE(RHO,P,T,X)	Density	kg/m^3
$s = f(p,t,x)$	s_ptx_He	SPTXHE(P,T,X)	C_SPTXHE(S,P,T,X)	Specific entropy	kJ/(kg K)
$t = f(p,h)$	t_ph_He	TPHHE(P,H)	C_TPHHE(T,P,H)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p,s)$	t_ps_He	TPSHE(P,S)	C_TPSHE(T,P,S)	Backward function: Temperature from pressure and entropy	°C
$t_{mel} = f(p)$	tmel_p_He	TMELPHE(P)	C_TMELPHE(TMEL,P)	Melting temperature from pressure	°C
$t_s = f(p)$	ts_p_He	TSPHE(P)	C_TSPHE(TS,P)	Saturation temperature from pressure	°C
$v = f(p,t,x)$	v_ptx_He	VPTXHE(P,T,X)	C_VPTXHE(V,P,T,X)	Specific volume	m^3/kg
$w = f(p,t,x)$	w_ptx_He	WPTXHE(P,T,X)	C_WPTXHE(W,P,T,X)	Isentropic speed of sound	m/s^2
$x = f(p,h)$	x_ph_He	XPHHE(P,H)	C_XPHHE(X,P,H)	Backward function: Vapor fraction from pressure and enthalpy	kg/kg
$x = f(p,s)$	x_ps_He	XPSHE(P,S)	C_XPSHE(X,P,S)	Backward function: Vapor fraction from pressure and entropy	kg/kg

Units: *t* in °C
p in bar
x in (kg of saturated steam)/(kg wet steam)

Details on the vapor fraction *x*

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

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.

If the state point to be calculated is located in the two phase region (wet steam), either the value 0 or 1 has to be entered for *x* (x = 0 for boiling liquid, x = 1 for saturated steam). Here the backward functions will result in x = 0 or x = 1.

If the state point to be calculated is located in the two phase region, 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 calculating wet steam and *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 quantity of the chosen function to be calculated results in –1000.

Wet steam region:

Temperature range from t_t = - 270.9732 °C bis t_c = - 267.9485 °C
Pressure range from p_t = 0.04856476 bar bis p_c = 2.274751 bar

Values on the triple point and on the critical point

By means of McCarty's equation of state the exact values of the critical and the triple point have been calculated as follows:

Critical point: t_c = - 267.9485 °C
p_c = 2.27475064473337 bar

Triple point: t_t = - 270.9732 °C
p_t = 0.048564759143234 bar

Range of validity

Temperature range: from $t_{mel}(p)$ to 1226.85 °C at $p \geq p_t$ = 0.04856476 bar

and

from t_t = - 270.9732 °C to 1226.85 °C at $p < p_t$ = 0.04856476 bar

Pressure range: from 0.001 bar to 1000 bar

Reference state

$h = h' = 0$ and $s = s' = 0$

at $p = p_n$ = 1.01325 bar (Standard atmospheric pressure)

and $t = t_s(p_n)$ = - 268.92 °C

Note:

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

2 Application of FluidLAB in MATLAB

The FluidLAB Add-In has been developed to calculate thermodynamic properties in MATLAB®. Within FluidLAB, it enables the direct call of functions relating to helium from the LibHe property library.

2.1 Installing FluidLAB

Installing FluidLAB including LibHe for 32-bit MATLAB®

This section describes the installation of FluidLAB LibHe for a 32-bit version of MATLAB®.

Before you begin, it is best to close any Windows® applications, since Windows® may need to be rebooted during the installation process.

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

CD_FluidLAB_LibHe

in your Windows Explorer®, Norton Commander® or another similar program you are using.

Open this folder by double-clicking on it.

In this folder you will see the following files:

FluidLAB_LibHe_Docu_Eng.pdf
FluidLAB_LibHe_Setup.exe
LibHe.dll.

In order to run the installation of FluidLAB including, the LibHe property library, double-click on the file

FluidLAB_LibHe_Setup.exe.

Installation may start with a window noting that all Windows® programs should be closed. When this is the case, the installation can be continued. Click the "Next >" button.

In the following dialog box, "Destination Location", the default path offered automatically for the installation of FluidLAB is

C:\Program Files\FluidLAB\LibHe	(for English version of Windows)
C:\Programme\FluidLAB\LibHe	(for German version of Windows).

By clicking the "Browse…" button, you can change the installation directory before installation (see Figure 2.1).

Figure 2.1: "Destination Location"

If you wish to change directories, click the "Browse…" button and select your desired directory. The instructions in this documentation refer to the stated default directory. Leave this window by clicking the "Next >" button.

The dialog window "Start Installation" appears. Click the "Next >" button to continue installation. The FluidLAB files are now being copied into the created directory on your hard drive. Click the "Finish >" button in the following window to complete installation.

The installation program has copied the following files

:capt_ico_big.ico	LC.dll
libifcoremd.dll	limmd.dll
libiomp5md.dll	LibHe.dll

for LibHe into the directory

"C:\Program Files\FluidLAB\LibHe"	(for English version of Windows)
"C:\Programme\FluidLAB\LibHe"	(for German version of Windows)

Now, you have to overwrite the file "LibHe.dll" in your FluidLAB directory with the file of the same name provided on your CD with FluidLAB.

To do this, open the CD in "My Computer" and click on the file "LibHe.dll" in order to highlight it.

Then click on the "Edit" menu in your Explorer and select "Copy".

Now, open your FluidLAB directory (the standard being

C:\Program Files\FluidLAB\LibHe	(for English version of Windows)
C:\Programme\FluidLAB\LibHe	(for German version of Windows))

and insert the file "LibHe.dll" by clicking the "Edit" menu in your Explorer and then select "Paste". Answer the question whether you want to replace the file by clicking the "Yes" button. Now, you have overwritten the file "LibHe.dll" successfully and the property functions are available in MATLAB.

Installing FluidLAB including LibHe for 64-bit MATLAB®

This section describes the installation of FluidLAB LibHe.

Before you begin, it is best to close any Windows® applications, since Windows® may need to be rebooted during the installation process.

After you have downloaded and extracted the zip-file "CD_FluidLAB_LibHe_x64.zip", you will see the folder

CD_FluidLAB_LibHe

in your Windows Explorer®, Norton Commander® or other similar program you are using.

Open this folder by double-clicking on it.

In this folder you will see the following two files:

FluidLAB_LibHe_Docu_Eng.pdf
FluidLAB_LibHe_64_Setup.msi
LibHe.dll
Setup.exe.

In order to run the installation of FluidLAB including, the LibHe property library, double-click on the file

Setup.exe.

Installation of FluidLAB LibHe starts with a window noting that the installer will guide you through the installation process. Click the "Next >" button to continue.

In the following dialog box, "Destination Location", the default path offered automatically for the installation of FluidLAB is

C:\Program Files\FluidLAB\LibHe (for English version of Windows)
C:\Programme\FluidLAB\LibHe (for German version of Windows)

By clicking the "Browse…" button, you can change the installation directory before installation (see Figure 2.2).

Figure 2.2: "Select Installation Folder"

Finally, click on "Next >" to continue installation; click "Next >" again in the "Confirm Installation" window which follows in order to start the installation of FluidLAB.

After FluidLAB has been installed, you will see the sentence "FluidLAB LibHe 64 has been successfully installed." Confirm this by clicking the "Close" button.

The installation program has copied the following files for LibHe into the directory

"C:\Program Files\FluidLAB\LibHe" (for English version of Windows)
"C:\Programme\FluidLAB\LibHe" (for German version of Windows):

capt_ico_big.ico	libifcoremd.dll
LC.dll	libiomp5md.dll
LibHe.dll	libmmd.dll

Now, you have to overwrite the file "LibHe.dll" in your FluidLAB directory with the file of the same name provided on your CD with FluidLAB.
To do this, open the CD in "My Computer" and click on the file "LibHe.dll" in order to highlight it. Then click on the "Edit" menu in your Explorer and select "Copy".
Now, open your FluidLAB directory (the standard being C:\Program Files\FluidLAB\LibHe) and insert the file "LibHe.dll" by clicking the "Edit" menu in your Explorer and then select "Paste". Answer the question whether you want to replace the file by clicking the "Yes" button. Now, you have overwritten the file "LibHe.dll" successfully and the property functions are available in MATLAB.

The installation programs for both the 32-bit and the 64-bit Windows version have copied the following function files for LibHe into the directory

"C:\Program Files\FluidLAB\LibHe" (for English version of Windows)
"C:\Programme\FluidLAB\LibHe" (for German version of Windows):

- Dynamic Link Library "LibHe.dll" and other necessary system DLL files.

- MATLAB®-Interface-Programme for calculable functions

a_ptx_He	ps_T_He
cp_ptx_He	rho_ptx_He
cv_ptx_He	s_ptx_He
eta_ptx_He	t_ph_He
h_ptx_He	t_ps_He
kappa_ptx_He	tmel_p_He
lam_ptx_He	ts_p_He
mue_ptx_He	v_ptx_He
nue_ptx_He	w_ptx_He
pmel_t_He	x_ph_He
Pr_ptx_He	x_ps_He

Please note that there is a difference in the file extension of the function files.

The 32-bit installation program has copied function files with the file extension

.mexw32

and the 64-bit installation program has copied function files with the file extension

.mexw64

into your LibHe directory (the standard being

C:\Program Files\FluidLAB\LibHe (for English version of Windows)
C:\Programme\FluidLAB\LibHe (for German version of Windows).

2.2 Licensing the LibHe Property Library

The licensing procedure must be carried out when the prompt message appears. In this case, you will see the "License Information" window for LibHe (see figure below).

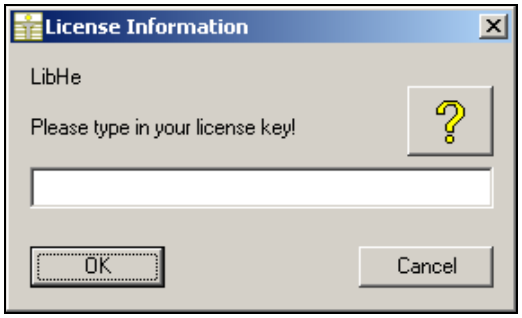

Figure 2.3: "License Information" window

Here you are asked to type in the license key which you have obtained from the Zittau/Goerlitz University of Applied Sciences. If you do not have this, or have any questions, you will 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:

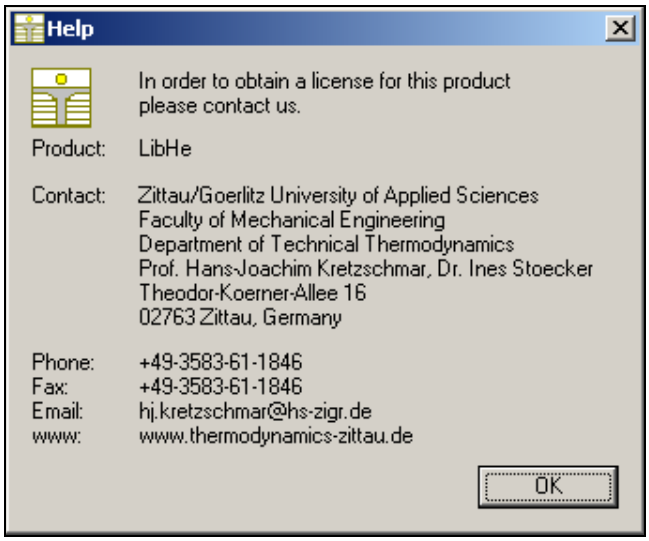

Figure 2.4: "Help" window

If you do not enter a valid license it is still possible to use MATLAB® by clicking "Cancel" twice. In this case, the LibHe property library will display the result "–11111111" for every calculation.

The "License Information" window will appear every time you use FluidLAB LibHe until you enter a license code to complete registration. If you decide not to use FluidLAB LibHe, you can uninstall the program following the instructions given in section 2.5 of this User's Guide.

2.3 Example: Calculation of the Specific Enthalpy *h* = f(*p*,*t*,*x*) for Helium in an M-File

Now we will calculate, step by step, the specific enthalpy *h* as a function of pressure *p*, temperature *t* and vapor fraction *x* for helium using FluidLAB.

Please carry out the following instructions:

- Start Windows-Explorer, Total Commander, My Computer or another file manager program.
  The following description refers to Windows-Explorer
- Your Windows-Explorer should be set to Details for a better view. Click the "Views" button and select "Details".
- Switch into the program directory of FluidLAB in which you will find the folder "\LibHe"; in the standard case:

  "C:\Program Files\FluidLAB" (for English version of Windows)
  "C:\Programme\FluidLAB" (for German version of Windows)

- Create the folder "\LibHe_Example". Click "File", then click "New" in the pop-up menu and afterwards select "Folder". Name the new folder "\LibHe_Example ".
- You will see the following window:

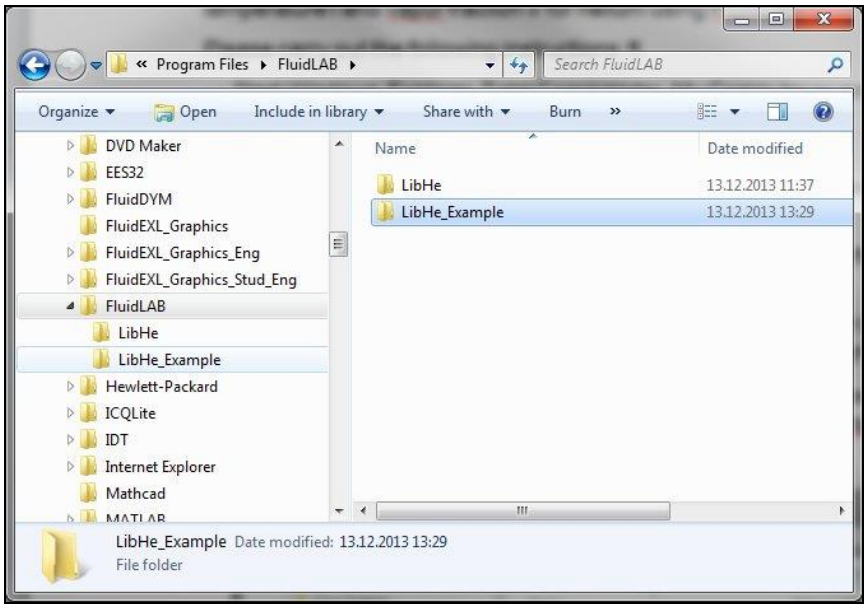

Figure 2.5: Folders "LibHe" and "LibHe_Example"

- Switch into the directory "\LibHe" within "\FluidLAB", the standard being:
  "C:\Program Files\FluidLAB" (for English version of Windows)
  "C:\Programme\FluidLAB" (for German version of Windows)

- If you have installed the 32-bit version of FluidLAB LibHe you will see the following window:

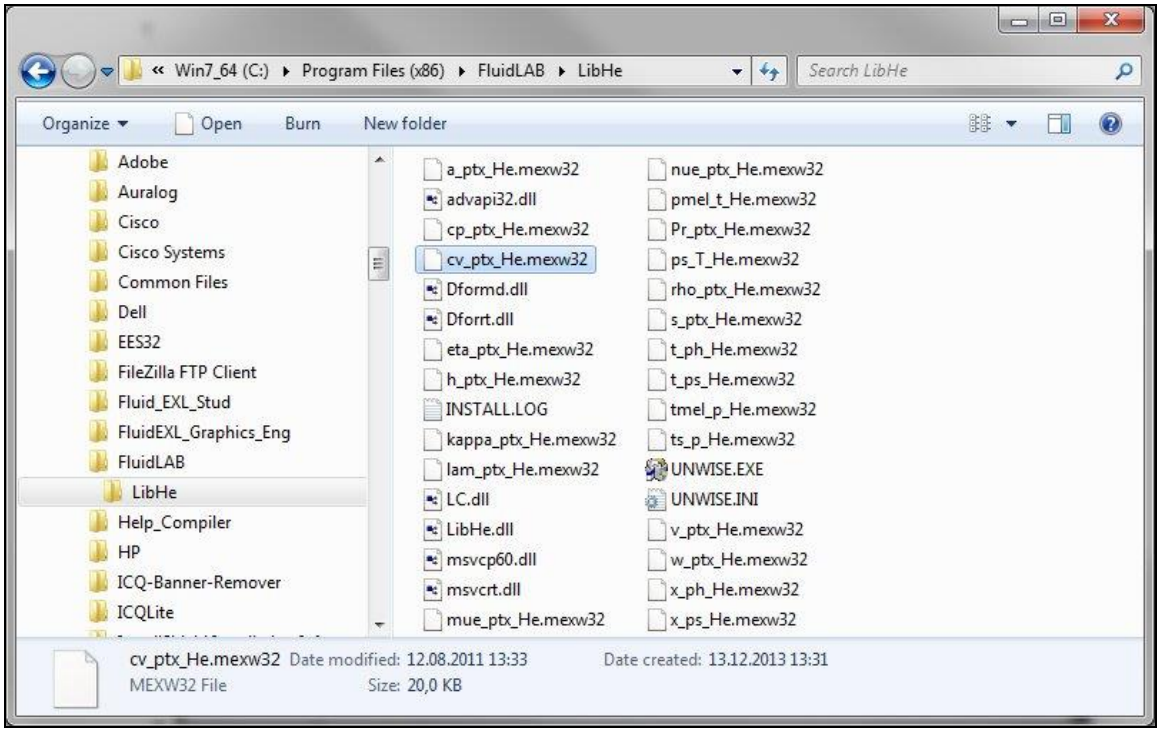

Figure 2.6: Contents of the folder "LibHe" (32-bit version)

- If you have installed the 64-bit version of FluidLAB LibHe you will see the following window:

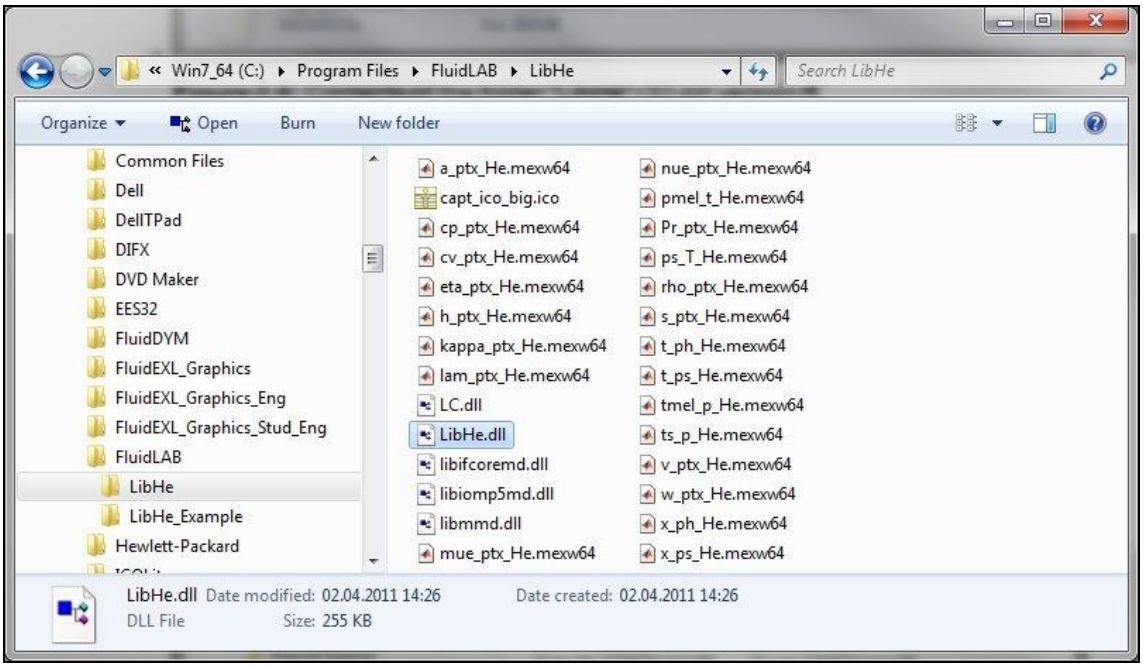

Figure 2.7: Contents of the folder "LibHe" (64-bit version)

If you have installed the **32-bit** version of LibHe you will now have to copy the following files into the directory

"C:\Program Files\FluidLAB\LibHe_Example" (for English version of Windows)
"C:\Programme\FluidLAB\LibHe_Example" (for German version of Windows)

in order to calculate the function $h = f(p,t,x)$.

- The following files are needed:
  - "advapi32.dll"
  - "Dformd.dll"
  - "Dforrt.dll"
  - "h_ptx_He.mexw32"
  - "LibHe.dll"
  - "LC.dll.dll"
  - "msvcp60.dll"
  - "msvcrt.dll"
- Click the file "h_ptx_He.mexw32", then click "Edit" in the upper menu bar and select "Copy".
- Switch into the directory

  "C:\Program Files\FluidLAB\LibHe_Example" (for English version of Windows)
  "C:\Programme\FluidLAB\LibHe_Example" (for German version of Windows),

  click "Edit" and select "Paste".
- Repeat these steps in order to copy the other files listed above.
- You will see the following window:

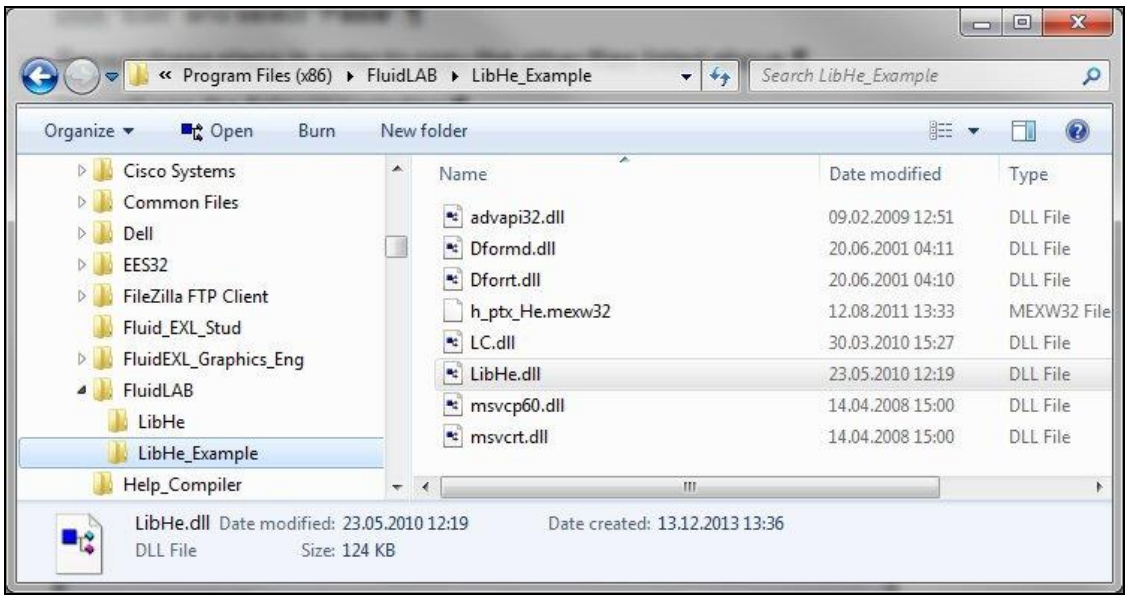

Figure 2.8: Contents of the folder "LibHe_Example" (32-bit)

If you have installed the **64-bit** version of LibHe you will now have to copy the following files into the directory

"C:\Program Files\FluidLAB\LibHe_Example" (for English version of Windows)

"C:\Programme\FluidLAB\LibHe_Example" (for German version of Windows)

in order to calculate the function $h = f(p,t,x)$.

- The following files are needed:
  - "h_ptx_He.mexw64"
  - "LC.dll"
  - "LibHe.dll"
  - "libifcoremd.dll"
  - "libiomp5.dll"
  - "libmmd.dll."
- Click the file "h_ptx_LibHe.mexw64", then click "Edit" in the upper menu bar and select "Copy."
- Switch into the directory

  "C:\Program Files\FluidLAB\LibHe_Example" (for English version of Windows)

  "C:\Programme\FluidLAB\LibHe_Example" (for German version of Windows),

click "Edit" and then "Paste."

- Repeat these steps in order to copy the other files listed above. You may also select all the above-named files and then copy them as a group (press the Control button to enable multiple markings).
- You will see the following window:

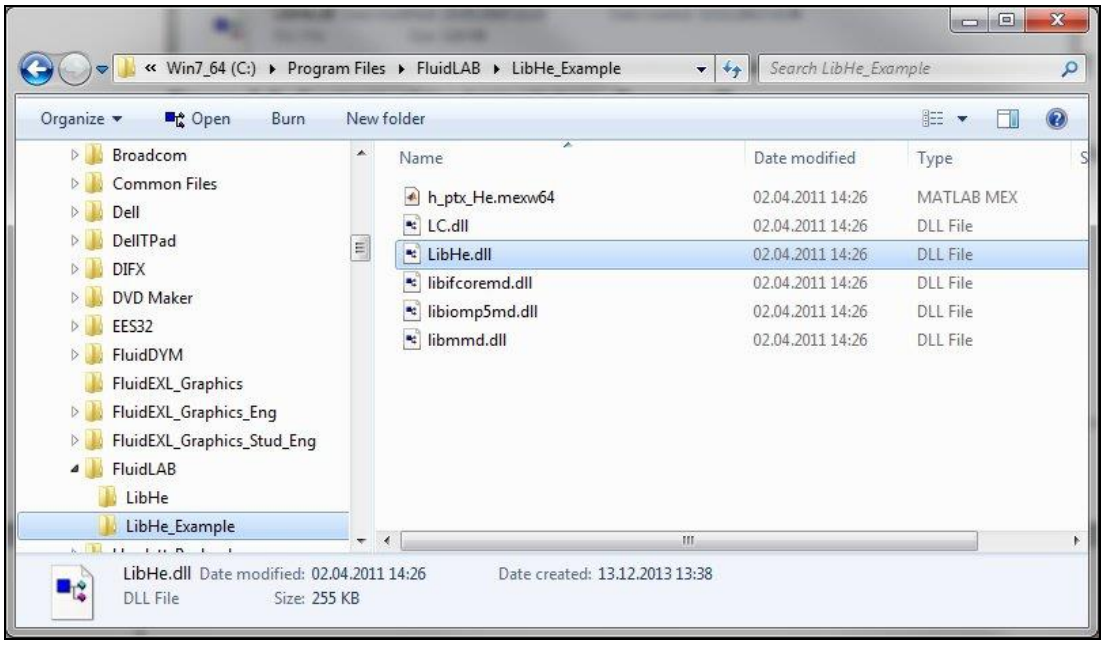

Figure 2.9: Contents of the folder "LibHe_Example" (64-bit)

- Start MATLAB® (if you have not started it already).
- Click the button marked in the next figure in order to open the folder "\LibHe_Example" in the "Current Directory" window.

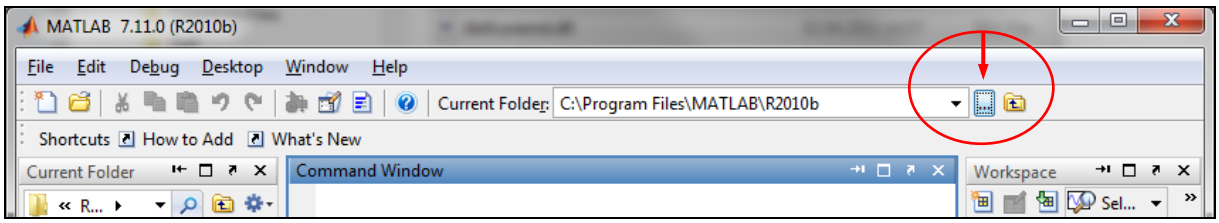

Figure 2.10: Selection of the working directory

- Find and select the directory

  "C:\Program Files\FluidLAB\LibHe_Example" (for English version of Windows)
  "C:\Programme\FluidLAB\LibHe_Example" (for German version of Windows)

  in the menu which appears (see the following figure).

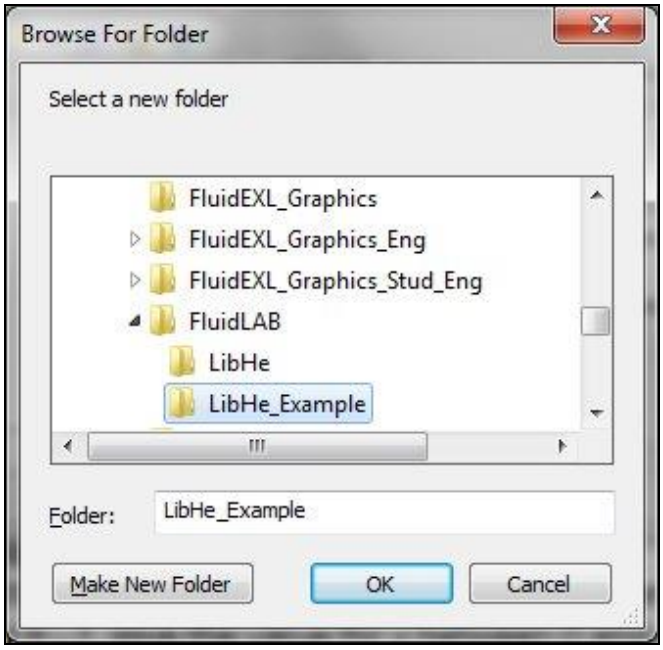

Figure 2.11: Choosing the "LibHe_Example" folder

- Confirm your selection by clicking the "OK" button.
- First of all you need to create an M–File in MATLAB®. Within MATLAB® click "File", then select "New" and afterwards click "M-File" in MATLAB 2006 or earlier versions or click "Script" in MATLAB R2010.
- If the "Editor" window appears as a separate window, you can embed it into MATLAB® by clicking the insertion arrow (see next figure) in order to obtain a better view.

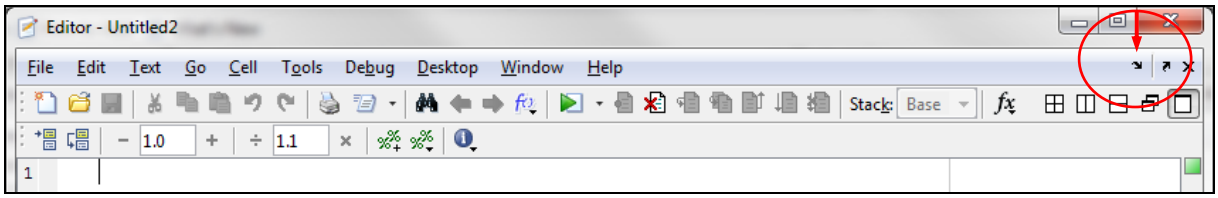

Figure 2.12: Embedding the "Editor" window

- In the figure below you will see the "Editor - Untitled" window.

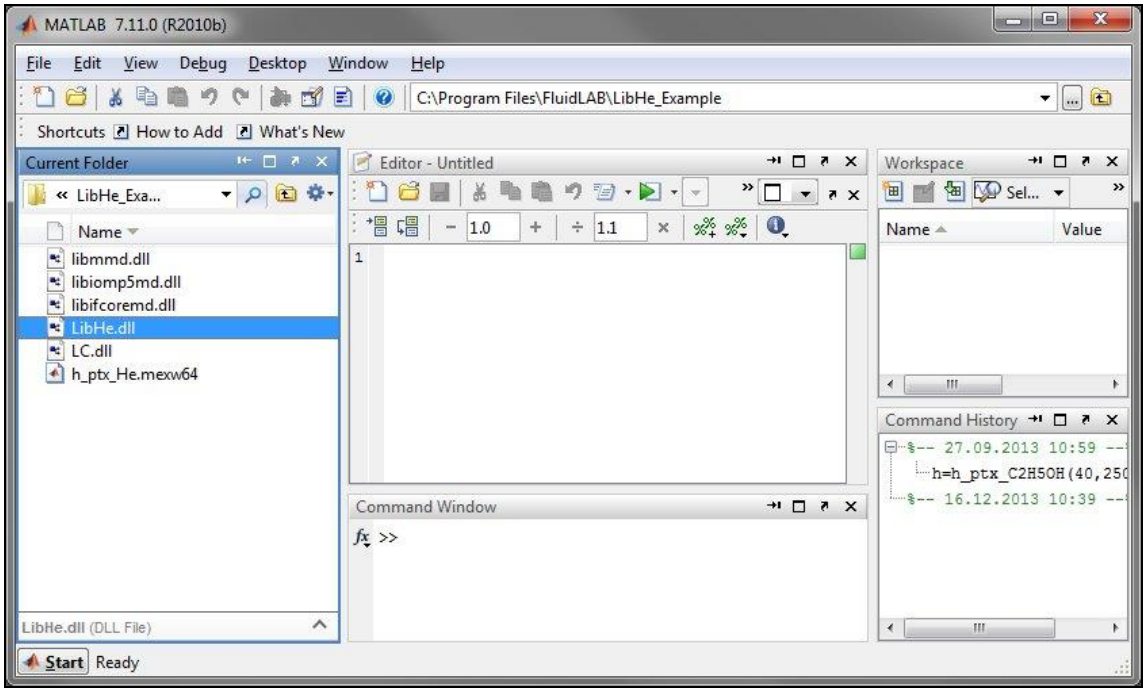

Figure 2.13: Embedded "Editor" window

- Now type the following lines in the "Editor - Untitled" window:

Text to be written:	Explanation:
`% h_ptx_He.m`	file name as comment
`%%`	paragraph separation
`p=10; % pressure in bar`	declaration of the variables pressure, temperature and vapor fraction
`t=25; % temperature in °C`	
`x=-1; % vapor fraction`	
`%%`	paragraph separation
`h=h_ptx_He(p,t,x)`	function call
`%%`	paragraph separation

- Remarks:

  - The program interprets the first line which starts with " % " to be a data description in "Current Directory"
  - Paragraph separations which are mandatory are being realised through " %%". By this, declaration of variables and calculation instructions are also being separated.
  - The words which are printed in green, start with " % " and stand behind the variables are comments. In fact they are not necessary but they are reasonable for your overview and comprehensibility.
  - You have to leave out the semicolons behind the numerical values if you wish to see the result for *h* and the input parameters as well.

  The values of the function parameters in their corresponding units stand for:

  - First operand: Value for p = 10 bar
    (Range of validity: p = 0.001 bar ... 1000 bar)
  - Second operand: Value for t = 25 °C
    (Range of validity: $t = t_{mel}$ ... 1226.85 °C)
  - Third operand: Value for x = -1

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

  Single-phase region

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

  Wet-steam region

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

  When calculating wet steam either the given value for *t* and p = -1 or the given value for *p* and t = -1 and in both cases the value for *x* between 0 and 1 must be entered.

  If *p* and *t* and *x* are entered as given values, the program considers *p* and *t* to be appropriate to represent the vapor pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

  (Vapor pressure curve of Helium:
  t_t = -270.He32 °C ... t_c = 267.9485 °C
  p_t = 0.048564759143234 bar ... p_c = 2.27475064473337 bar)

- Save the "M-File" by clicking the "File" button and then click "Save As...".

- The menu "Save file as:" appears; In this menu, the folder name "LibHe_Example" must be displayed in the "Save in:" field

- Next to "File name" you have to type in "Example_h_ptx_He.m" and afterwards click the "Save" button.

Note.
The name of the example file has to be different in comparison to the name of the used function. For example, the file could not be named "h_ptx_He.m" in this case. Otherwise an error message will appear during the calculation.

- You will now see the following window:

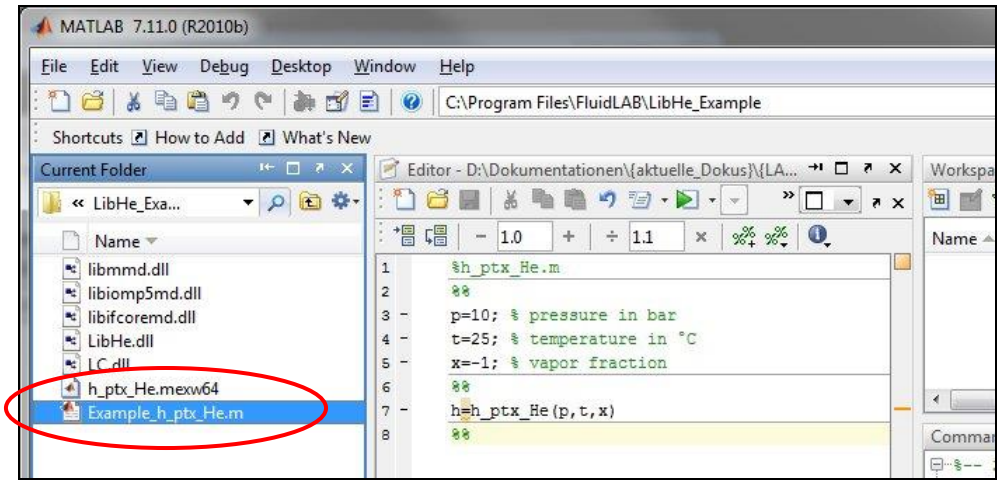

Figure 2.14: "Example_h_ptx_He.m" M-file

- Within the "Current Directory" window the file "Example_h_ptx_He.m" appears.
- Right-click this file and select "Run" in the menu which appears (see next Figure).

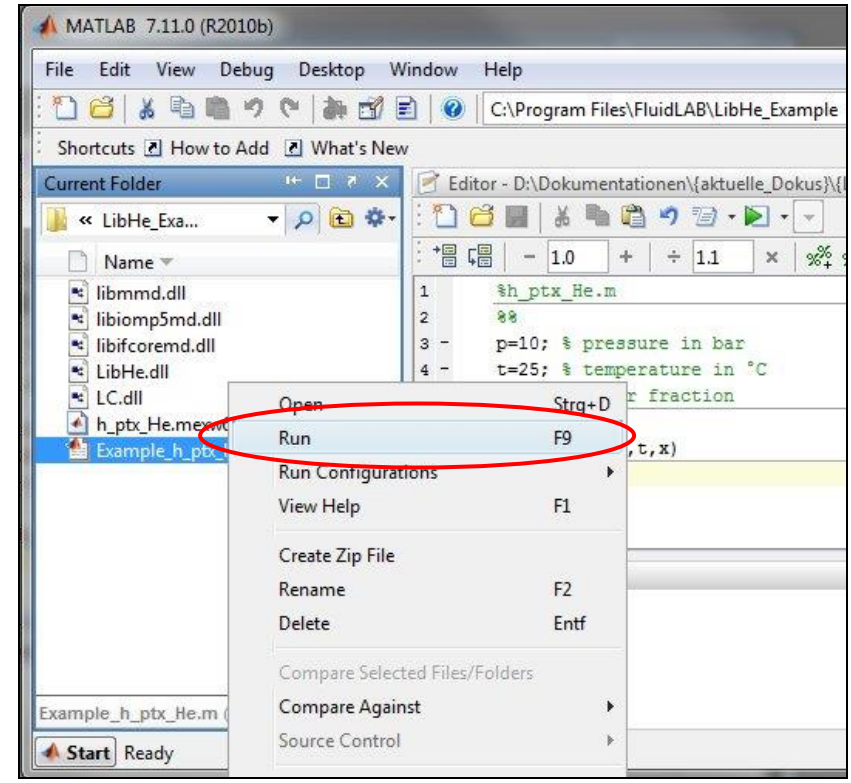

Figure 2.15: Running the "Example_h_ptx_He.m" M-file

- You will see the following window:

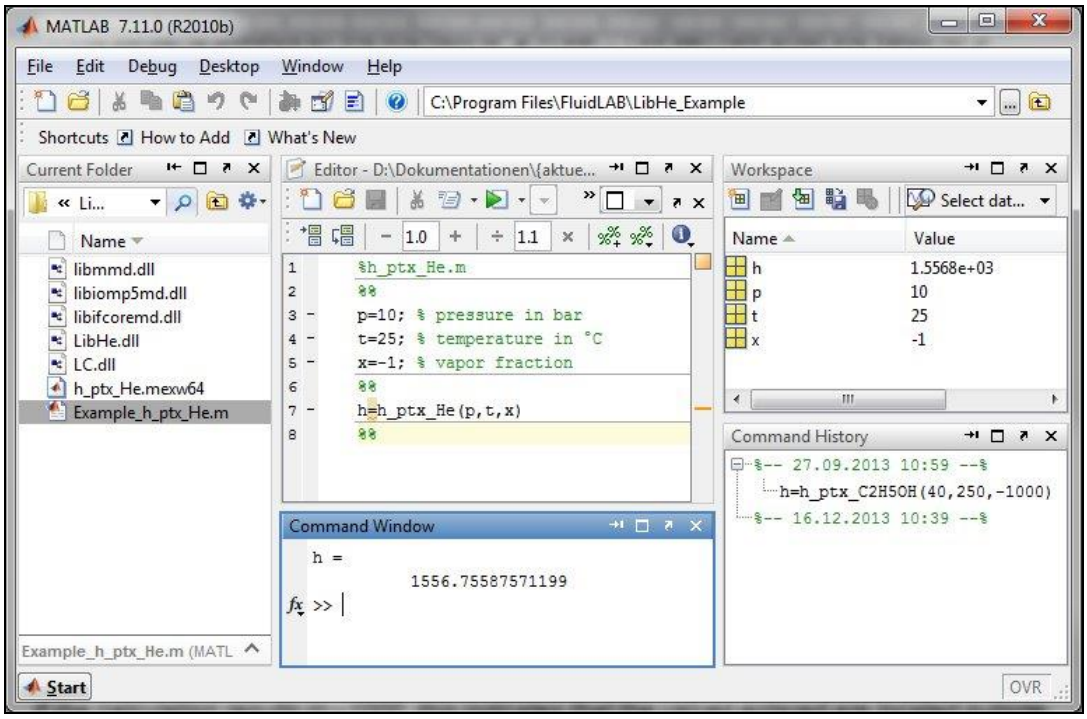

Figure 2.16: MATLAB® with calculated result

The result for *h* appears in the "Command Window".

⇒ The result in our sample calculation here is: "h = 1556.75587571199". The corresponding unit is kJ/kg (see table of the property functions in Chapter 1).

To be able to calculate other values, you have to copy the associated mexw32 or mexw64 files as well because MATLAB® can only access functions that are located in the "Current Directory" window. The example calculated can be found in the directory

C:\Program Files\FluidLAB\He_Example" (for English version of Windows)

C:\Programme\FluidLAB\He_Example" (for German version of Windows),

and you may use it as a basis for further calculations using FluidLAB.

Hint!

If the input values are located outside the range of validity of LibHe, the calculation of the chosen function to be calculated function results in -1000. You can find more exact details on every function and its corresponding range of validity in the enclosed program documentation in Chapter 3.

2.4 Example: Calculation of the Specific Enthalpy *h* = f(*p*,*t*,*x*) for Helium in the Command Window

- Please follow the instructions from page 2/6 to 2/9.
- Start MATLAB® (if you have not started it already).
- Click the button marked in the following figure in order to open the folder "\LibHe_Example" in the window "Current Directory".

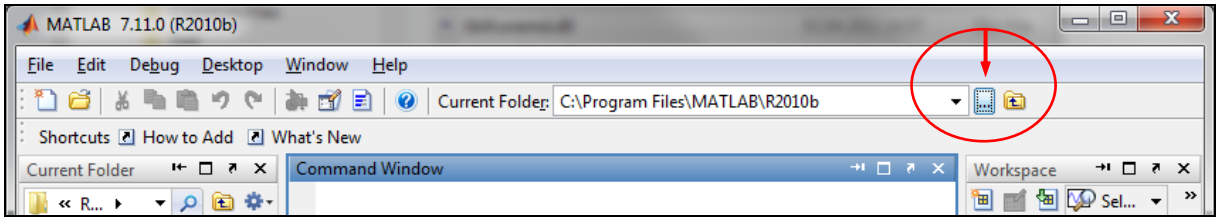

Figure 2.17: Selection of the working directory

- Find and select the directory

  "C:\Program Files\FluidLAB\LibHe_Example"(for English version of Windows)
  "C:\Programme\FluidLAB\LibHe_Example" (for German version of Windows)

  in the menu that appears (see figure below).

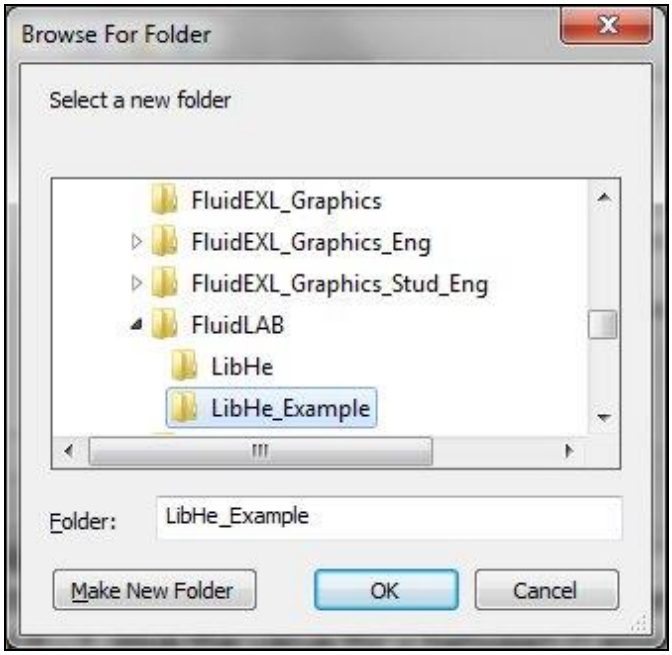

Figure 2.18: Choosing the "LibHe_Example" folder

- Confirm your selection by clicking the "OK" button.

- You will see the following window:

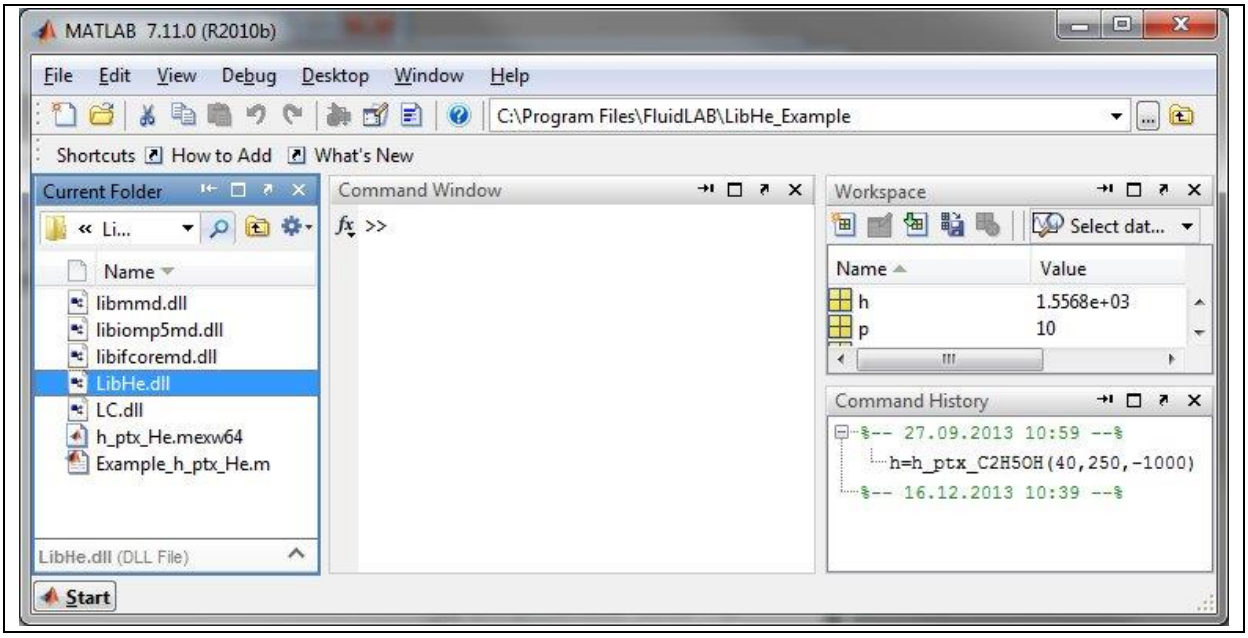

Figure 2.19: MATLAB® with necessary files

Corresponding to the table of property functions in Chapter 1 you have to call up the function "**h_ptx_He**" as follows for calculating h=f(p,t,x):

- Write "**h=h_ptx_He(10,25,-1)**" within the "Command Window".

The values of the function parameters in their corresponding units stand for:

- First operand: Value for p = 10 bar
  (Range of validity: p = 0.001 bar ... 1000 bar)
- Second operand: Value for t = 25 °C
  (Range of validity: $t = t_{mel}$ ... 1226.85 °C)
- Third operand: Value for x = -1

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:

<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.

<u>Wet-steam region</u>

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

When calculating wet steam either the given value for t and p = -1 or the given value for p and t = -1 and in both cases the value for x between 0 and 1 must be entered.

If p and t and x are entered as given values, the program considers p and t to be appropriate to represent the vapor pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

(Vapor pressure curve of Helium:

t_t = -270.He32 °C ... t_c = 267.9485 °C

p_t = 0.048564759143234 bar ... p_c = 2.27475064473337 bar)

- Confirm your entry by pressing the "ENTER" button.
- You will see the following window:

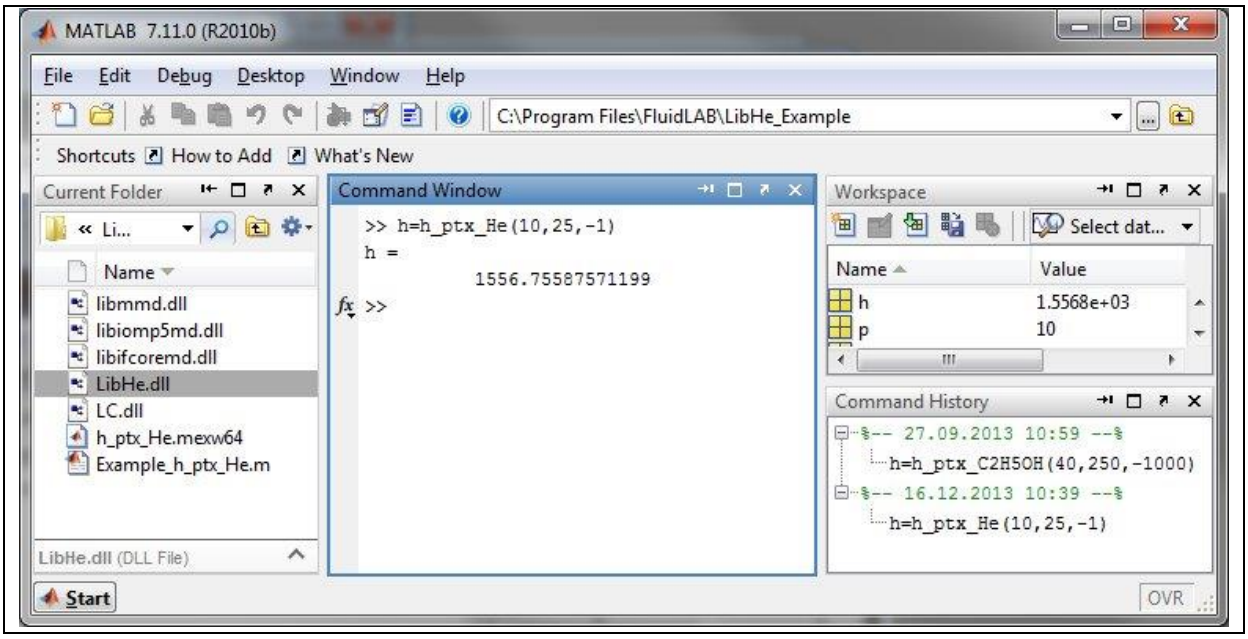

Figure 2.20: MATLAB® with calculated result

In the "Command Window" you will see the result "h = 1556.75587571199". The corresponding unit is kJ/kg (see table of the property functions in chapter 1).

To be able to calculate other values, you will have to copy the respective mexw32 or mexw64 files into the working directory as well, because MATLAB® can only access functions that are located in the "Current Directory" window. The example calculated can be found in the directory

C:\Program Files\FluidLAB\LibHe_Example" (for English version of Windows)
C:\Programme\FluidLAB\LibHe_Example" (for German version of Windows),

and you may use it as a basis for further calculations using FluidLAB.

Note:

If the input values are located outside the range of validity, the result for the chosen function to be calculated results in -1000. You can find more exact details on every function and its corresponding range of validity in the enclosed program documentation in Chapter 3.

2.4 Using FluidLAB with SIMULINK

To use the functions of FluidLAB with the simulation program SIMULINK you have to start SIMULINK in MATLAB® by clicking on Simulink in the upper menu bar shown in Figure 2.19.

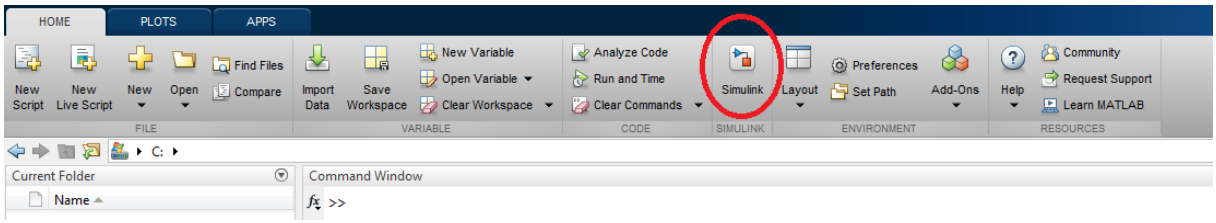

Figure 2.21: Starting Simulink

Then choose a blank model or a simulation in which you would like to use FluidLAB. Now you need to add a MATLAB function block that you can find in the library browser shown in Figure 2.22.

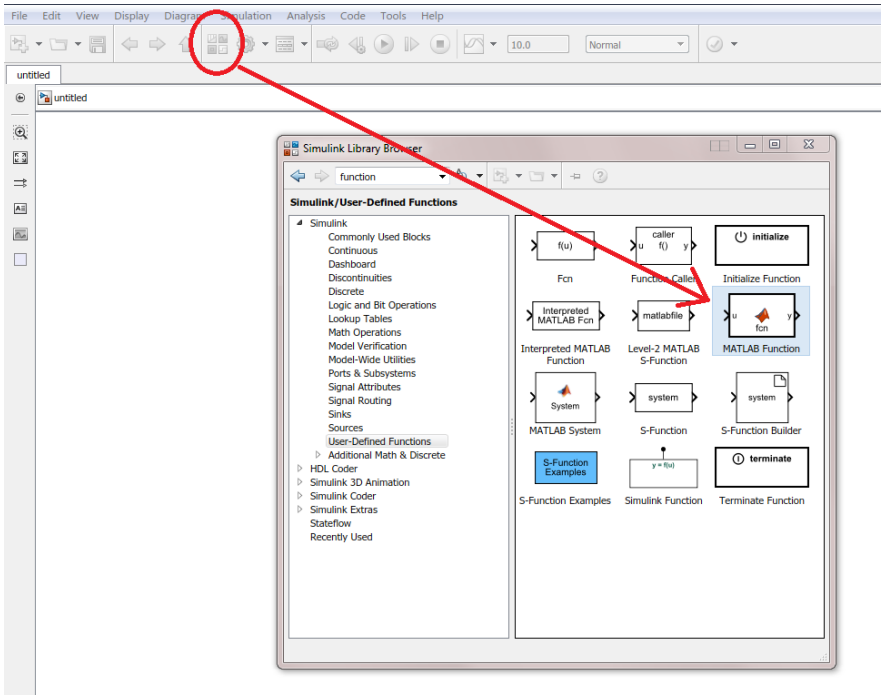

Figure 2.22: Simulink library browser and choosing a MATLAB Function

By dragging and dropping you can drag a Simulink block in your model. The function needs inputs and output that you can find in the Simulink library browser under sources and sinks. For this example constants were taken for the inputs and a display block were taken for outputting.

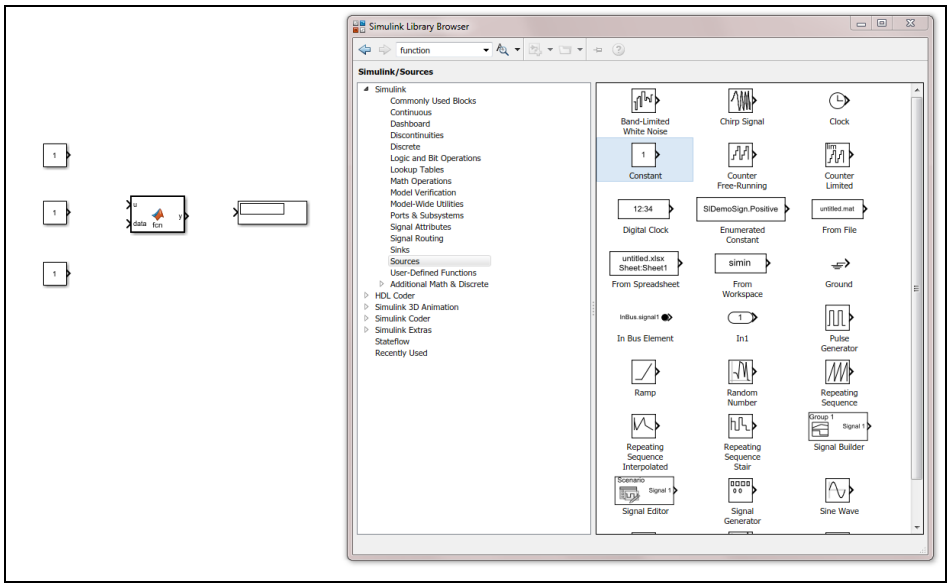

Figure 2.23: Inputs and outputs of the example

Now you have to link inputs and outputs to the MATLAB function block. By pressing and holding the left mouse button on the arrow of a block, you can draw a line and drag it to the MATLAB function block. With this method you can link all blocks together.

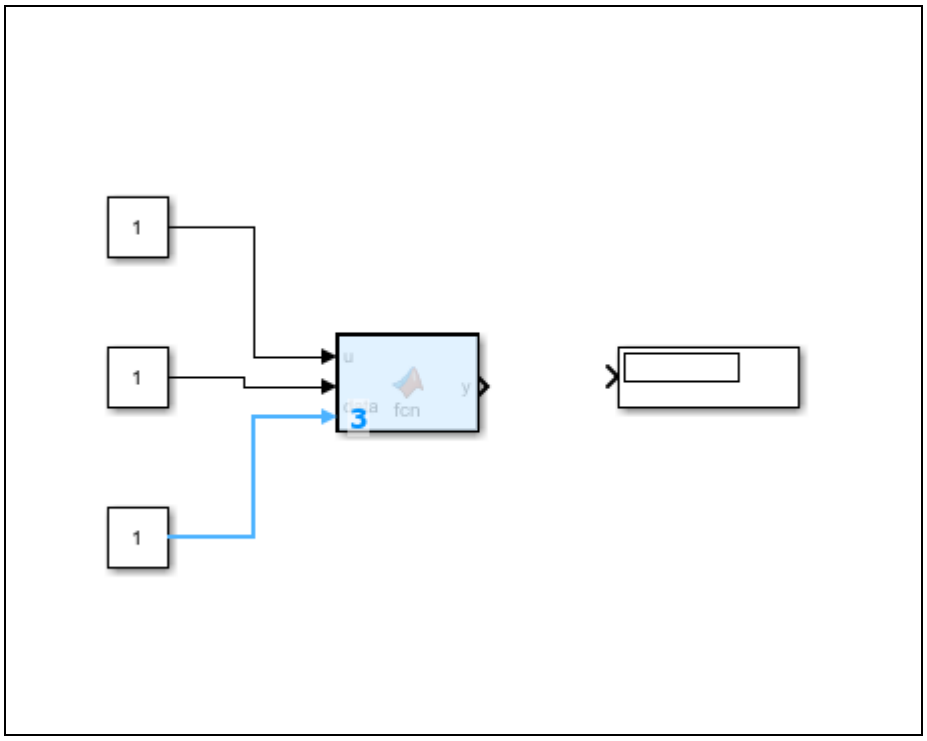

Figure 2.24: Linking blocks in Simulink

You can define the value of a constant block by double-click on them. If you want to calculate the example use the values you can find in section 2.3. With a double-click on the MATLAB function block you can define the function in MATLAB®. The following source code is for the example calculation and the table below describes the source code closer. You can adapt these few lines to call all other function of FluidLAB.

```
function h = fcn(p, t, x)
coder.extrinsic('addpath');
```

```
coder.extrinsic('h_ptx_He');
addpath('C:\Program Files\FluidLAB\LibHE');
h = h_ptx_He(p,t,x);
```

Matlab source code	Explanation
`function h = fcn(p, t, x)`	function header, you can define the function name and the inputs like p, t and x of the example
`coder.extrinsic('addpath');`	necessary to add a path
`coder.extrinsic('h_ptx_He');`	Choose the function name of the FluidLAB function
`addpath('C:\Program Files\FluidLAB\LibHE');`	Add the installation path of FluidLAB
`h = h_ptx_He(p,t,x);`	Linking the FluidLAB function to the MATLAB function block

You can copy and paste the sourcecode in MATLAB® or write it into the MATLAB® editor. The simulation will start by clicking the run button in Matlab or Simulink and you can see the example in the display block of the simulation which is shown in figure 2.23.

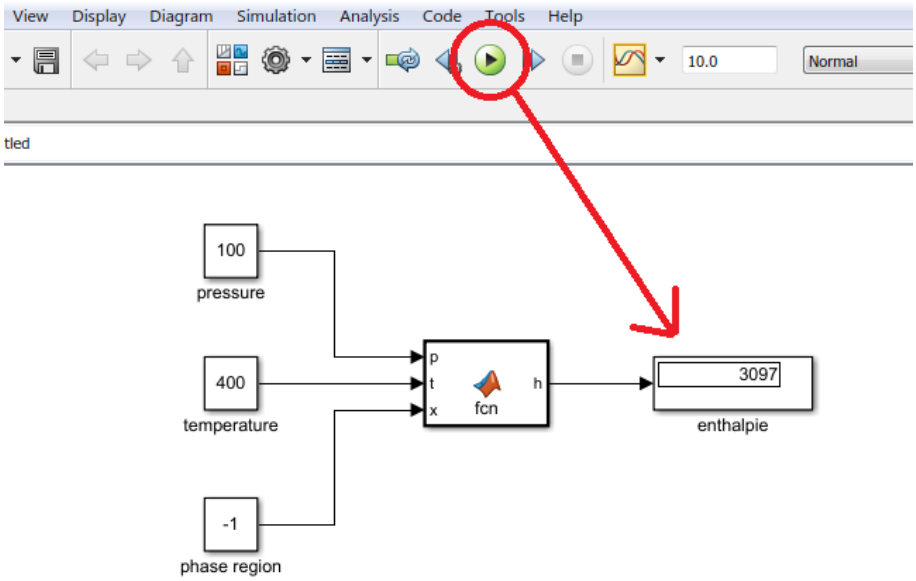

Figure 2.25: Starting the simulation and result of the calculation

Your result is may an other than shown in figure 2.25. If you want to calculate the example please use the values from section 2.3.

2.5 Removing FluidLAB including LibHe

To remove the LibHe property library from your hard drive in Windows®, click "Start" in the Windows® task bar, select "Settings" and click "Control Panel".

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

Now double-click on "Add or Remove Programs". In the list box of the "Add or Remove Programs" window that appears select "FluidLAB LibHe" by clicking on it and click the "Change/Remove" button.

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

Confirm the following menu "Perform Uninstall" by clicking the "Finish" button.

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

Now, FluidLAB has been removed.

If there is no library other than LibHe installed, the directory "FluidLAB" will be removed as well.

3. Program Documentation

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

Function Name:	**a_ptx_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION APTXHE(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_APTXHE(A,P,T,X)** REAL*8 A,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

APTXHE, **A** or **a_ptx_He** – Thermal diffusivity $a = \frac{\lambda \cdot v}{c_p}$ in m^2/s

Range of validity

Temperature range: from $t_{mel}(p)$ to 1226.85 °C at $p \geq p_t = 0.04856476$ bar,

from $t_t = -270.9732$ °C to 1226.85 °C at $p \leq p_t = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 bar

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

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

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

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

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for *t* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* (x = 0 or x = 1). If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the vapor pressure curve. If this is not the case the calculation results in -1000.

Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = -270.9732$ °C to $t_c = -267.9485$

Pressure ranges from $p_t = 0.04856476$ bar to $p_c = 2.274751$ bar

Results for wrong input values

Result **APTXHE = - 1000**, **A = -1000** or **a_ptx_He = -1000** for input values:

Single phase region:
(*x* = -1)
p > 1000 bar or *p* < 0.001 bar or
$t > 1226.85$ °C or $t < t_{mel}(p)$ at $p \geq p_t = 0.048564759143234$ bar or
$t < t_t = -270.9732$ °C at $p < p_t = 0.048564759143234$ bar

Saturation lines:
at *p* = -1000 and *t* > - 267.9485 °C or *t* < - 270.9732 °C
at *t* = -1000 and *p* > 2.27475064473337 bar or *p* < 0.048564759143234 bar or

at p > 2.27475064473337 bar or p < 0.048564759143234 bar and
t > - 267.9485 °C or t < - 270.9732 °C

References: [25], [26], [27]

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

Function Name:	**cp_ptx_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION CPPTXHE(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_CPPTXHE(CP,P,T,X)** REAL*8 CP,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

CPPTXHE, **CP** or **cp_ptx_He** - Specific isobaric heat capacity c_p in kJ/kg K

Range of validity

Temperature range: from $t_{mel}(p)$ to 1226.85 °C at $p \geq p_t = 0.04856476$ bar,

from $t_t = -270.9732$ °C to 1226.85 °C at $p \leq p_t = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 bar

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

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

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

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

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x (x = 0 or x = 1). If p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve. If this is not the case the calculation results in -1000.

Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = -270.9732$ °C to $t_c = -267.9485$

Pressure ranges from $p_t = 0.04856476$ bar to $p_c = 2.274751$ bar

Results for wrong input values

Result **CPPTXHE = - 1000**, **CP = -1000** or **cp_ptx_He = -1000** for input values:

Single phase region:
(x = -1)
p > 1000 bar or p < 0.001 bar or
$t > 1226.85$ °C or $t < t_{mel}(p)$ at $p \geq p_t = 0.048564759143234$ bar or
$t < t_t = -270.9732$ °C at $p < p_t = 0.048564759143234$ bar

Saturation lines:
at p = -1000 and t > - 267.9485 °C or t < - 270.9732 °C
at t = -1000 and p > 2.27475064473337 bar or p < 0.048564759143234 bar or
at p > 2.27475064473337 bar or p < 0.048564759143234 bar and
t > - 267.9485 °C or t < - 270.9732 °C

References: [25]

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

Function Name:	**cv_ptx_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION CVPTXHE(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_CVPTXHE(CV,P,T,X)** REAL*8 CV,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

CVPTXHE, **CV** or **cv_ptx_He** - Specific isobaric heat capacity c_V in kJ/kg K

Range of validity

Temperature range: from $t_{mel}(p)$ to 1226.85°C at $p \geq p_t = 0.04856476$ bar,

from $t_t = -270.9732$°C to 1226.85°C at $p \leq p_t = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 bar

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

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

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

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

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for *t* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* (x = 0 or x = 1). If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the vapor pressure curve. If this is not the case the calculation results in -1000.

Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = -270.9732$°C to $t_c = -267.9485$

Pressure ranges from $p_t = 0.04856476$ bar to $p_c = 2.274751$ bar

Results for wrong input values

Result **CVPTXHE = - 1000**, **CV = -1000** or **cv_ptx_He = -1000** for input values:

Single phase region:
(x = -1)

p > 1000 bar or p < 0.001 bar or
$t > 1226.85$°C or $t < t_{mel}(p)$ at $p \geq p_t = 0.048564759143234$ bar or
$t < t_t = -270.9732$°C at $p < p_t = 0.048564759143234$ bar

Saturation lines:

at p = -1000 and t > - 267.9485 °C or t < - 270.9732 °C
at t = -1000 and p > 2.27475064473337 bar or p < 0.048564759143234 bar or
at p > 2.27475064473337 bar or p < 0.048564759143234 bar and
t > - 267.9485 °C or t < - 270.9732 °C

References: [25]

Dynamic Viscosity η = f(p,t,x)

Function Name:	**eta_ptx_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION ETAPTXHE(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_ETAPTXHE(ETA,P,T,X)** REAL*8 ETA,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

ETAPTXHE, **ETA** or **eta_ptx_He** - Dynamic viscosity η in Pa s

Range of validity

Temperature range: from $t_{mel}(p)$ to 1226.85°C at $p \geq p_t = 0.04856476$ bar,

from $t_t = -270.9732$°C to 1226.85°C at $p \leq p_t = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 bar

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

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

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

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

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x (x = 0 or x = 1). If p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve. If this is not the case the calculation results in -1000.

Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = -270.9732$°C to $t_c = -267.9485$

Pressure ranges from $p_t = 0.04856476$ bar to $p_c = 2.274751$ bar

Results for wrong input values

Result **ETAPTXHE = - 1000**, **ETA = -1000** or **eta_ptx_He = -1000** for input values:

Single phase region:
(x = -1)

p > 1000 bar or p < 0.001 bar or
$t > 1226.85$°C or $t < t_{mel}(p)$ at $p \geq p_t = 0.048564759143234$ bar or
$t < t_t = -270.9732$°C at $p < p_t = 0.048564759143234$ bar

Saturation lines:

at p = -1000 and t > - 267.9485 °C or t < - 270.9732 °C
at t = -1000 and p > 2.27475064473337 bar or p < 0.048564759143234 bar or
at p > 2.27475064473337 bar or p < 0.048564759143234 bar and
t > - 267.9485 °C or t < - 270.9732 °C

References: [25], [26]

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

Function Name:	**h_ptx_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION HPTXHE(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_HPTXHE(H,P,T,X)** REAL*8 H,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

HPTXHE, **H** or **h_ptx_He** - Specific enthalpy *h* in kJ/kg

Range of validity

Temperature range: from $t_{mel}(p)$ to $1226.85\,°C$ at $p \geq p_t = 0.04856476$ bar,

from $t_t = -270.9732\,°C$ to $1226.85\,°C$ at $p \leq p_t = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 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:

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

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

When calculating wet steam either the given value for *t* <u>and</u> p = -1000 or the given value for *p* <u>and</u> t = -1000 and in both cases the value for *x* between 0 and 1 must be entered.

If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program considers *p* and *t* to be appropriate to represent the vapor pressure curve. If this is not the case, the calculation results in -1000.

Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = -270.9732\,°C$ to $t_c = -267.9485$

Pressure ranges from $p_t = 0.04856476$ bar to $p_c = 2.274751$ bar

Results for wrong input values

Result **HPTXHE = - 1000**, **H = -1000** or **h_ptx_He = -1000** for input values:

Single phase region:
(*x* = -1)
p > 1000 bar or *p* < 0.001 bar or
$t > 1226.85\,°C$ or $t < t_{mel}(p)$ at $p \geq p_t = 0.048564759143234$ bar or
$t < t_t = -270.9732\,°C$ at $p < p_t = 0.048564759143234$ bar

Saturation lines:
at *p* = -1000 and *t* > - 267.9485 °C or *t* < - 270.9732 °C
at *t* = -1000 and *p* > 2.27475064473337 bar or *p* < 0.048564759143234 bar or
at *p* > 2.27475064473337 bar or *p* < 0.048564759143234 bar and
t > - 267.9485 °C or *t* < - 270.9732 °C

References: [25]

Isentropic Exponent κ = f(p,t,x)

Function Name:	**kappa_ptx_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION KAPPTXHE(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_KAPPTXHE(KAP,P,T,X)** REAL*8 KAP,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

KAPPTXHE, **KAP** or **kappa_ptx_He** - Isentropic exponent $\kappa = \dfrac{w^2}{p \cdot v}$

Range of validity

Temperature range: from $t_{\mathrm{mel}}(p)$ to 1226.85°C at $p \geq p_{\mathrm{t}} = 0.04856476$ bar,

from $t_{\mathrm{t}} = -270.9732$°C to 1226.85°C at $p \leq p_{\mathrm{t}} = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 bar

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

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

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

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

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x (x = 0 or x = 1). If p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve. If this is not the case the calculation results in -1000.

Saturated liquid and saturated vapor line:

Temperature ranges from $t_{\mathrm{t}} = -270.9732$°C to $t_{\mathrm{c}} = -267.9485$

Pressure ranges from $p_{\mathrm{t}} = 0.04856476$ bar to $p_{\mathrm{c}} = 2.274751$ bar

Results for wrong input values

Result **KAPPTXHE**, **KAP = -1000** or **kappa_ptx_He = -1000** for input values:

Single phase region:
(x = -1)
p > 1000 bar or p < 0.001 bar or
$t > 1226.85$°C or $t < t_{\mathrm{mel}}(p)$ at $p \geq p_{\mathrm{t}} = 0.048564759143234$ bar or
$t < t_{\mathrm{t}} = -270.9732$°C at $p < p_{\mathrm{t}} = 0.048564759143234$ bar

Saturation lines:
at p = -1000 and t > - 267.9485 °C or t < - 270.9732 °C
at t = -1000 and p > 2.27475064473337 bar or p < 0.048564759143234 bar or
at p > 2.27475064473337 bar or p < 0.048564759143234 bar and
t > - 267.9485 °C or t < - 270.9732 °C

References: [25]

Thermal Conductivity λ = f(p,t,x)

Function Name:	**lambda_ptx_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION LAMPTXHE(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_LAMPTXHE(LAM,P,T,X)** REAL*8 LAM,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

LAMPTXHE, **LAM** or **lambda_ptx_He** - Thermal conductivity λ in W / m K

Range of validity

Temperature range: from $t_{mel}(p)$ to 1226.85 °C at $p \geq p_t = 0.04856476$ bar,

from $t_t = -270.9732$ °C to 1226.85 °C at $p \leq p_t = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 bar

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

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

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

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

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x (x = 0 or x = 1). If p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve. If this is not the case the calculation results in -1000.

Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = -270.9732$ °C to $t_c = -267.9485$

Pressure ranges from $p_t = 0.04856476$ bar to $p_c = 2.274751$ bar

Results for wrong input values

Result **LAMPTXHE = - 1000**, **LAM = -1000** or **lambda_ptx_He = -1000** for input values:

Single phase region:
(x = -1)

p > 1000 bar or p < 0.001 bar or
$t > 1226.85$ °C or $t < t_{mel}(p)$ at $p \geq p_t = 0.048564759143234$ bar or
$t < t_t = -270.9732$ °C at $p < p_t = 0.048564759143234$ bar

Saturation lines:

at p = -1000 and t > - 267.9485 °C or t < - 270.9732 °C
at t = -1000 and p > 2.27475064473337 bar or p < 0.048564759143234 bar or
at p > 2.27475064473337 bar or p < 0.048564759143234 bar and
t > - 267.9485 °C or t < - 270.9732 °C

References: [25], [27]

Joule-Thomson-Coefficient μ = f(p,t,x)

Function Name:	**mue_ptx_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION MUEPTXHE(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_MUEPTXHE(MUE,P,T,X)** REAL*8 MUE,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

MUEPTXHE, **MUE** or **mue_ptx_He** - Joule-Thomson-Coefficient μ in K/bar

Range of validity

Temperature range: from $t_{mel}(p)$ to 1226.85°C at $p \geq p_t = 0.04856476$ bar,

from $t_t = -270.9732$°C to 1226.85°C at $p \leq p_t = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 bar

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

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

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

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

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x (x = 0 or x = 1). If p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve. If this is not the case the calculation results in -1000.

Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = -270.9732$°C to $t_c = -267.9485$

Pressure ranges from $p_t = 0.04856476$ bar to $p_c = 2.274751$ bar

Results for wrong input values

Result **MUEPTXHE = - 1000**, **MUE = -1000** or **mue_ptx_He = -1000** for input values:

Single phase region:
(x = -1)

p > 1000 bar or p < 0.001 bar or
$t > 1226.85$°C or $t < t_{mel}(p)$ at $p \geq p_t = 0.048564759143234$ bar or
$t < t_t = -270.9732$°C at $p < p_t = 0.048564759143234$ bar

Saturation lines:

at p = -1000 and t > - 267.9485 °C or t < - 270.9732 °C
at t = -1000 and p > 2.27475064473337 bar or p < 0.048564759143234 bar or
at p > 2.27475064473337 bar or p < 0.048564759143234 bar and
t > - 267.9485 °C or t < - 270.9732 °C

References: [25]

Kinematic Viscosity ν = f(p,t,x)

Function Name:	**nue_ptx_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION NUEPTXHE(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_NUEPTXHE(NUE,P,T,X)** REAL*8 NUE,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

NUEPTXHE, **NUE** or **nue_ptx_He -** Kinematic viscosity $\nu = \eta \cdot v$ in m^2/s

Range of validity

Temperature range: from $t_{mel}(p)$ to 1226.85°C at $p \geq p_t = 0.04856476$ bar,

from $t_t = -270.9732$°C to 1226.85°C at $p \leq p_t = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 bar

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

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

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

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

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x (x = 0 or x = 1). If p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve. If this is not the case the calculation results in -1000.

Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = -270.9732$°C to $t_c = -267.9485$

Pressure ranges from $p_t = 0.04856476$ bar to $p_c = 2.274751$ bar

Results for wrong input values

Result **NUEPTXHE = - 1000**, **NUE = -1000** or **nue_ptx_He = -1000** for input values:

Single phase region:
(x = -1)

p > 1000 bar or p < 0.001 bar or
$t > 1226.85$°C or $t < t_{mel}(p)$ at $p \geq p_t = 0.048564759143234$ bar or
$t < t_t = -270.9732$°C at $p < p_t = 0.048564759143234$ bar

Saturation lines:

at p = -1000 and t > - 267.9485 °C or t < - 270.9732 °C
at t = -1000 and p > 2.27475064473337 bar or p < 0.048564759143234 bar or
at p > 2.27475064473337 bar or p < 0.048564759143234 bar and
t > - 267.9485 °C or t < - 270.9732 °C

References: [25], [26]

Melting Pressure p_{mel} = f(t)

Function Name:	**pmel_t_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION PMELTHE(T)** REAL*8 T
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_PMELHE(PMEL,T)** REAL*8 PMEL, T

Input Values:

T - Temperature t in °C

Result

PMELTHE, **PMEL** or **pmel_t_He** - Melting pressure p_{mel} in bar

Range of validity

Temperature range: from - 270.9732 °C to - 259.2557 °C

Results for wrong input values

Result **PMELTHE = -1000**, **PMEL = -1000** or **pmel_t_He = -1000** for input values:

t > - 259.2557 °C or t < - 270.9732 °C

References: [25]

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

Function Name:	**Pr_ptx_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION PRPTXHE(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_PRPTXHE(PR,P,T,X)** REAL*8 PR,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

PRPTXHE, **PR** or **Pr_ptx_He** – Prandtl-Number $Pr = \frac{\eta \cdot c_p}{\lambda}$

Range of validity

Temperature range: from $t_{mel}(p)$ to 1226.85°C at $p \geq p_t = 0.04856476$ bar,

from $t_t = -270.9732$°C to 1226.85°C at $p \leq p_t = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 bar

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

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

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

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

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for *t* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* (x = 0 or x = 1). If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the vapor pressure curve. If this is not the case the calculation results in -1000.

Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = -270.9732$°C to $t_c = -267.9485$

Pressure ranges from $p_t = 0.04856476$ bar to $p_c = 2.274751$ bar

Results for wrong input values

Result **PRPTXHE = - 1000**, **PR = -1000** or **Pr_ptx_He = -1000** for input values:

Single phase region:
(*x* = -1)

p > 1000 bar or *p* < 0.001 bar or
$t > 1226.85$°C or $t < t_{mel}(p)$ at $p \geq p_t = 0.048564759143234$ bar or
$t < t_t = -270.9732$°C at $p < p_t = 0.048564759143234$ bar

Saturation lines:

at *p* = -1000 and *t* > - 267.9485 °C or *t* < - 270.9732 °C
at *t* = -1000 and *p* > 2.27475064473337 bar or *p* < 0.048564759143234 bar or
at *p* > 2.27475064473337 bar or *p* < 0.048564759143234 bar and
t > - 267.9485 °C or *t* < - 270.9732 °C

References: [25], [26], [27]

Vapor Pressure p_s = f(t)

Function Name:	**ps_t_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION PSTHE(T)** REAL*8 T
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_PSTHE(PS,T)** REAL*8 PS,T

Input Values:

T - Temperature t in °C

Result

PSTHE, **PS** or **ps_t_He** - Vapor pressure p_s in bar

Range of validity

Temperature range: from $t_t = -270.9732$°C to $t_c = -267.9485$°C

Results for wrong input values

Result **PSTHE = -1000**, **PS = -1000** or **ps_t_He = -1000** for input values:

$t <$ - 270.9732 °C or $t >$ - 267.9485 °C

References: [25]

Density ρ = f(p,t,x)

Function Name:	**rho_ptx_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION RHOPTXHE(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_RHOPTXHE(RHO,P,T,X)** REAL*8 RHO,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

RHOPTXHE, **RHO** or **rho_ptx_He** - Density ρ in kg/m^3

Range of validity

Temperature range: from $t_{mel}(p)$ to 1226.85°C at $p \geq p_t = 0.04856476$ bar,

from $t_t = -270.9732$°C to 1226.85°C at $p \leq p_t = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 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:

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

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

When calculating wet steam either the given value for t <u>and</u> p = -1000 or the given value for p <u>and</u> t = -1000 and in both cases the value for x between 0 and 1 must be entered.

If p <u>and</u> t <u>and</u> x are entered as given values, the program considers p and t to be appropriate to represent the vapor pressure curve. If this is not the case, the calculation results in -1000.

Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = -270.9732$°C to $t_c = -267.9485$

Pressure ranges from $p_t = 0.04856476$ bar to $p_c = 2.274751$ bar

Results for wrong input values

Result **RHOPTXHE = - 1000**, **RHO = -1000** or **rho_ptx_He = -1000** for input values:

Single phase region:
(x = -1)

p > 1000 bar or p < 0.001 bar or
$t > 1226.85$°C or $t < t_{mel}(p)$ at $p \geq p_t = 0.048564759143234$ bar or
$t < t_t = -270.9732$°C at $p < p_t = 0.048564759143234$ bar

Saturation lines:

at p = -1000 and t > - 267.9485 °C or t < - 270.9732 °C
at t = -1000 and p > 2.27475064473337 bar or p < 0.048564759143234 bar or
at p > 2.27475064473337 bar or p < 0.048564759143234 bar and
t > - 267.9485 °C or t < - 270.9732 °C

References: [25]

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

Function Name:	**s_ptx_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION SPTXHE(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_SPTXHE(S,P,T,X)** REAL*8 S,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

SPTXHE, **S** or **s_ptx_He** - Specific entropy *s* in kJ/kg K

Range of validity

Temperature range: from $t_{mel}(p)$ to 1226.85 °C at $p \geq p_t = 0.04856476$ bar,

from $t_t = -270.9732$ °C to 1226.85 °C at $p \leq p_t = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 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:

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

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

When calculating wet steam either the given value for *t* <u>and</u> p = -1000 or the given value for *p* <u>and</u> t = -1000 and in both cases the value for *x* between 0 and 1 must be entered.

If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program considers *p* and *t* to be appropriate to represent the vapor pressure curve. If this is not the case, the calculation results in -1000.

Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = -270.9732$ °C to $t_c = -267.9485$

Pressure ranges from $p_t = 0.04856476$ bar to $p_c = 2.274751$ bar

Results for wrong input values

Result **SPTXHE = -1000**, **S = -1000** or **s_ptx_He = -1000** for input values:

Single phase region:
(*x* = -1)
p > 1000 bar or *p* < 0.001 bar or
$t > 1226.85$ °C or $t < t_{mel}(p)$ at $p \geq p_t = 0.048564759143234$ bar or
$t < t_t = -270.9732$ °C at $p < p_t = 0.048564759143234$ bar

Saturation lines:
at *p* = -1000 and *t* > - 267.9485 °C or *t* < - 270.9732 °C
at *t* = -1000 and *p* > 2.27475064473337 bar or *p* < 0.048564759143234 bar or
at *p* > 2.27475064473337 bar or *p* < 0.048564759143234 bar and
t > - 267.9485 °C or *t* < - 270.9732 °C

References: [25]

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

Function Name:	**t_ph_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION TPHHE(P,H)** REAL*8 P,H
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_TPHHE(T,P,H)** REAL*8 T,P,H

Input Values:

P - Pressure *p* in bar

H - Specific enthalpy *h* in kJ/kg

Result

TPHHE, **T** or **t_ph_He -** Temperature *t* in °C

Range of validity

Temperature range: from $t_{mel}(p)$ to 1226.85 °C at $p \geq p_t = 0.04856476$ bar,

from $t_t = -270.9732$ °C to 1226.85 °C at $p \leq p_t = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 bar

Details on the calculation of wet steam

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

Wet steam region:

Pressure ranges from $p_t = 0.04856476$ bar to $p_c = 2.274751$ bar

Results for wrong input values

Result **T_PH_HE**, **T = -1000** or **t_ph_He = -1000** for input values:

Single phase region:
(x = -1)
p > 1000 bar or p < 0.001 bar or
at the calculation result t > 1,226.85 °C or
$t < t_{mel}(p)$ at $p \geq p_t = 0.048564759143234$ bar or
$t < t_t = -270.9732$ °C at $p < p_t = 0.048564759143234$ bar

Saturation lines:
at p > 2.27475064473337 bar or p < 0.048564759143234 bar or
Calculation result t > - 267.9485 °C oder t < - 270.9732 °C

References: [25]

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

Function Name:	**t_ps_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION TPSHE(P,S)** REAL*8 P,S
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_TPSHE(T,P,S)** REAL*8 T,P,S

Input Values:

P - Pressure *p* in bar

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

Result

TPSHE, **T** or **t_ps_He -** Temperature *t* in °C

Range of validity

Temperature range: from $t_{mel}(p)$ to 1226.85 °C at $p \geq p_t = 0.04856476$ bar,

from $t_t = -270.9732$ °C to 1226.85 °C at $p \leq p_t = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 bar

Details on the calculation of wet steam

Details on the calculation of wet steam

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

Wet steam region:

Pressure ranges from $p_t = 0.04856476$ bar to $p_c = 2.274751$ bar

Results for wrong input values

Result **TPSHE, T = -1000** or **t_ps_He = -1000** for input values:

Single phase region:
(x = -1)
p > 1000 bar or p < 0.001 bar or
at the calculation result t > 1,226.85 °C or
$t < t_{mel}(p)$ at $p \geq p_t = 0.048564759143234$ bar or
$t < t_t = -270.9732$ °C at $p < p_t = 0.048564759143234$ bar

Saturation lines:
at p > 2.27475064473337 bar or p < 0.048564759143234 bar or
Calculation result t > - 267.9485 °C oder t < - 270.9732 °C

References: [25]

Saturation Temperature t_s = f(p)

Function Name:	**ts_p_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION TSPHE(P)** REAL*8 P
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_TSPHE(TS,P)** REAL*8 TS,P

Input Values:

P - Pressure p in bar

Result

TSPHE, **TS** or **ts_p_He** - Saturation temperature t_s in °C

Range of validity

Pressure range: from 0.001 bar to 1000 bar

Results for wrong input values

Result **TSPHE = -1000**, **TS = -1000** or **ts_p_He = -1000** for input values:

p < 0.048564759143234 bar or p > 2.27475064473337 bar

References: [25]

Melting Temperature t_{mel} = f(p)

Function Name:	**tmel_p_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION TMELHE(P)** REAL*8 P
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_TMELHE(TMEL,P)** REAL*8 TMEL,P

Input Values:

P - Pressure p in bar

Result

TMELPHE, **TMEL** or **tmel_p_He** - Melting temperature t_{mel} in °C

Range of validity

Pressure range: from 0.04856476 bar to 1000 bar

Results for wrong input values

Result **TMELHE, = -1000**, **TMEL = -1000** or **tmel_p_He = -1000** for input values:

p < 0.048564759143234 bar or p > 1000 bar

References: [25]

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

Function Name:	**v_ptx_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION VPTXHE(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_VPTXHE(V,P,T,X)** REAL*8 V,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

VPTXHE, **V** or **v_ptx_He** - Specific volume *v* in m^3/kg

Range of validity

Temperature range: from $t_{mel}(p)$ to 1226.85°C at $p \geq p_t = 0.04856476$ bar,

from $t_t = -270.9732$°C to 1226.85°C at $p \leq p_t = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 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:

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

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

When calculating wet steam either the given value for *t* <u>and</u> p = -1000 or the given value for *p* <u>and</u> t = -1000 and in both cases the value for *x* between 0 and 1 must be entered.

If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program considers *p* and *t* to be appropriate to represent the vapor pressure curve. If this is not the case, the calculation results in -1000.

Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = -270.9732$°C to $t_c = -267.9485$

Pressure ranges from $p_t = 0.04856476$ bar to $p_c = 2.274751$ bar

Results for wrong input values

Result **VPTXHE = -1000**, **V = -1000** or **v_ptx_He = -1000** for input values:

Single phase region:
(*x* = -1)
p > 1000 bar or *p* < 0.001 bar or
$t > 1226.85$°C or $t < t_{mel}(p)$ at $p \geq p_t = 0.048564759143234$ bar or
$t < t_t = -270.9732$°C at $p < p_t = 0.048564759143234$ bar

Saturation lines:
at *p* = -1000 and *t* > - 267.9485 °C or *t* < - 270.9732 °C
at *t* = -1000 and *p* > 2.27475064473337 bar or *p* < 0.048564759143234 bar or
at *p* > 2.27475064473337 bar or *p* < 0.048564759143234 bar and
t > - 267.9485 °C or *t* < - 270.9732 °C

References: [25]

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

Function Name:	**w_ptx_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION WPTXHE(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_WPTXHE(W,P,T,X)** REAL*8 W,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

WPTXHE, **W** or **w_ptx_He -** Speed of sound *w* in m/s

Range of validity

Temperature range: from $t_{mel}(p)$ to 1226.85°C at $p \geq p_t = 0.04856476$ bar,

from $t_t = -270.9732$°C to 1226.85°C at $p \leq p_t = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 bar

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

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

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

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

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for *t* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* (x = 0 or x = 1). If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the vapor pressure curve. If this is not the case the calculation results in -1000.

Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = -270.9732$°C to $t_c = -267.9485$

Pressure ranges from $p_t = 0.04856476$ bar to $p_c = 2.274751$ bar

Results for wrong input values

Result **WPTXHE = -1000** or **w_ptx_He = -1000** for input values:

Single phase region:
(*x* = -1)
p > 1000 bar or *p* < 0.001 bar or
$t > 1226.85$°C or $t < t_{mel}(p)$ at $p \geq p_t = 0.048564759143234$ bar or
$t < t_t = -270.9732$°C at $p < p_t = 0.048564759143234$ bar

Saturation lines:
at *p* = -1000 and *t* > - 267.9485 °C or *t* < - 270.9732 °C
at *t* = -1000 and *p* > 2.27475064473337 bar or *p* < 0.048564759143234 bar or
at *p* > 2.27475064473337 bar or *p* < 0.048564759143234 bar and
t > - 267.9485 °C or *t* < - 270.9732 °C

References: [25]

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

Function Name:	**x_ph_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION XPHHE(P,H)** REAL*8 P,H
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_XPHHE(T,P,H)** REAL*8 X,P,H

Input Values:

P - Pressure *p* in bar

H - Specific enthalpy *h* in kJ/kg

Result

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

Range of validity

Temperature range: from $t_{mel}(p)$ to $1226.85\,°C$ at $p \geq p_t = 0.04856476$ bar,

from $t_t = -270.9732\,°C$ to $1226.85\,°C$ at $p \leq p_t = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 bar

Details on the calculation of wet steam

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

Wet steam region:

Pressure ranges from $p_t = 0.04856476$ bar to $p_c = 2.274751$ bar

Results for wrong input values

Result **XPHHE**, **X = -1** or **x_ph_He = -1** for input values:

In case the state point is located in the single phase region

$p < 0.048564759143234$ bar or $p > 2.27475064473337$ bar

References: [25]

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

Function Name:	**x_ps_He**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION XPSHE(P,S)** REAL*8 P,S
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_XPSHE(X,P,S)** REAL*8 X,P,S

Input Values:

P - Pressure *p* in bar

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

Result

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

Range of validity

Temperature range: from $t_{mel}(p)$ to $1226.85\,°C$ at $p \geq p_t = 0.04856476$ bar,

from $t_t = -270.9732\,°C$ to $1226.85\,°C$ at $p \leq p_t = 0.04856476$ bar

Pressure range: from 0.001 bar to 1000 bar

Details on the calculation of wet steam

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

Wet steam region:

Pressure ranges from $p_t = 0.04856476$ bar to $p_c = 2.274751$ bar

Results for wrong input values

Result **XPSHE**, **X = -1** or **x_ps_He = -1** for input values:

In case the state point is located in the single phase region

p < 0.048564759143234 bar or p > 2.27475064473337 bar

References: [25]

KCE

KCE-ThermoFluidProperties
www.thermofluidprop.com

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
  - IAPWS-IF97-S03rev
  - IAPWS-IF97-S04
  - IAPWS-IF97-S05
- IAPWS Revised Advisory Note No. 3 on Thermodynamic Derivatives (2008)

Library LibSBTL_IF97
Library LibSBTL_95

Extremely fast property calculations according to the IAPWS Guideline 2015
Spline-based Table Look-up Method (SBTL)
applied to the
Industrial Formulation IAPWS-IF97
and to the
Scientific Formulation IAPWS-95
for Computational Fluid Dynamics and simulating non-stationary processes

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

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 (2012)

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)

For more information please contact:

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The following thermodynamic and transport properties can be calculated[a]:

Thermodynamic Properties

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

Transport Properties

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

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

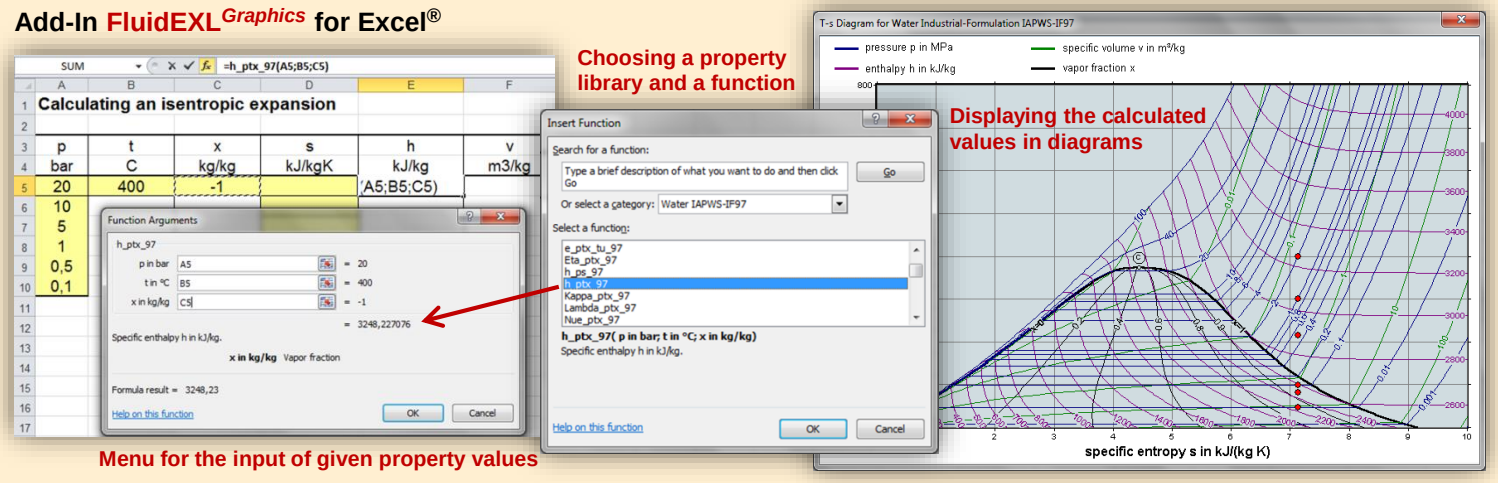
- Partial derivatives can be calculated.

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

KCE-ThermoFluidProperties
www.thermofluidprop.com

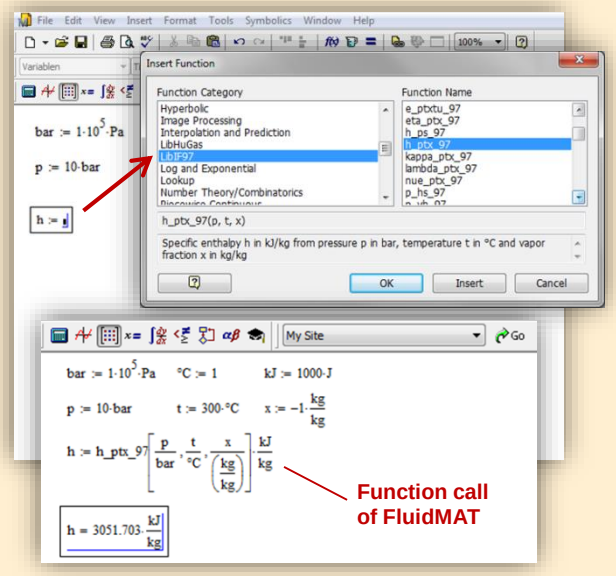
Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Add-In FluidEXL*Graphics* for Excel®



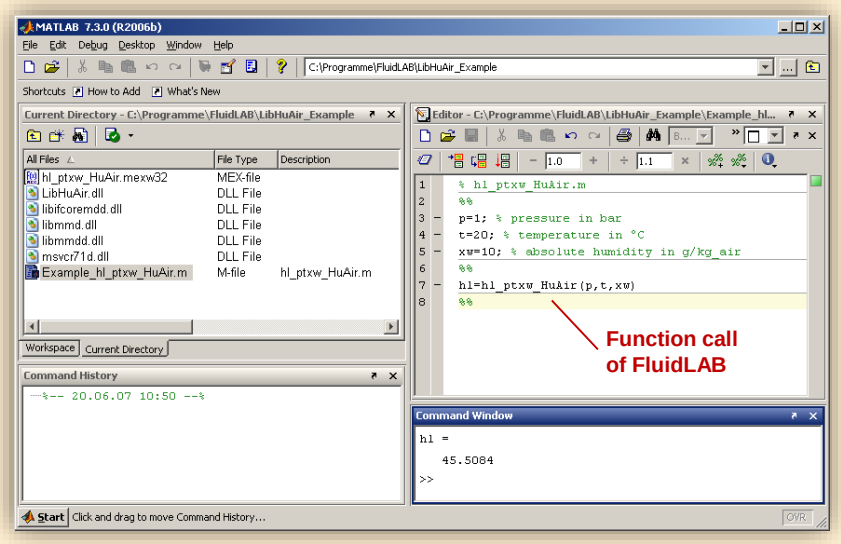
Add-In FluidMAT for Mathcad®

The property libraries can be used in Mathcad®.



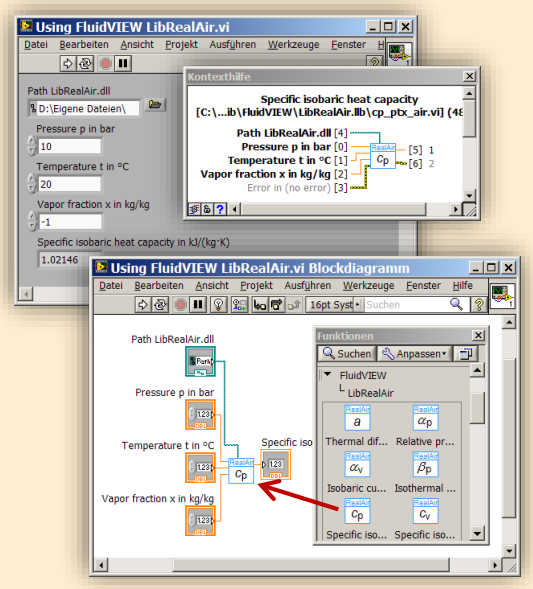
Add-In FluidLAB for MATLAB®

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



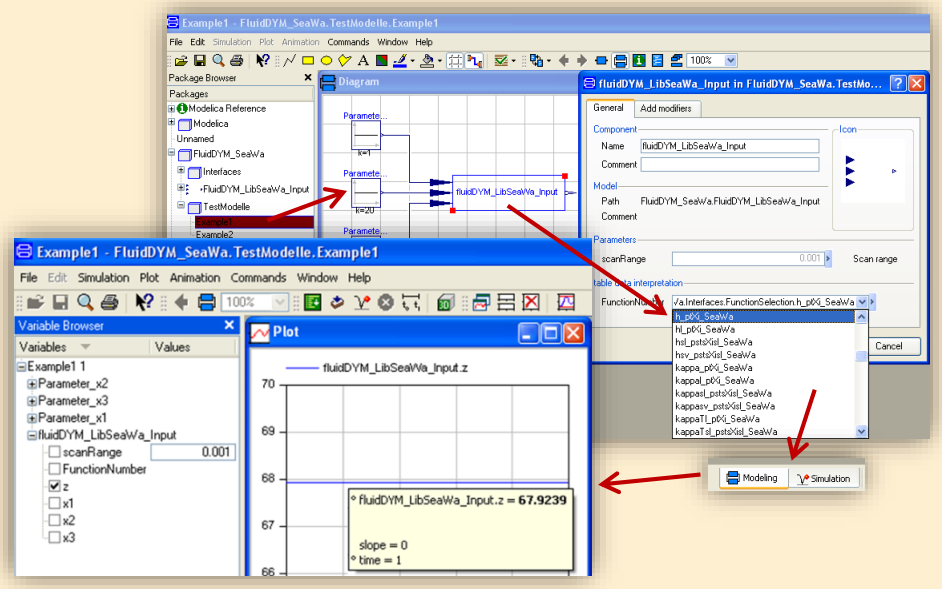
Add-On FluidVIEW for LabVIEW™

The property functions can be calculated in LabVIEW™.

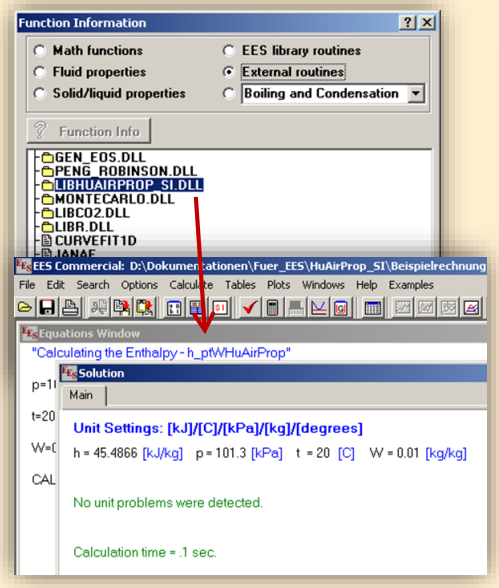


Add-In FluidDYM for DYMOLA® (Modelica) and SimulationX®

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

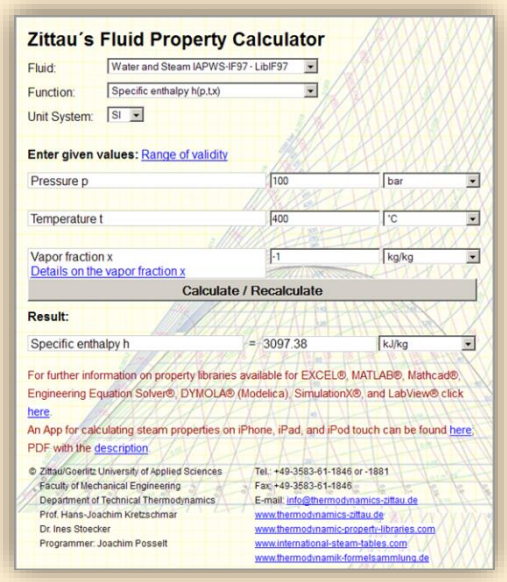


Add-In FluidEES for Engineering Equation Solver®



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

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

Thermodynamic Properties

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

Transport Properties

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

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 can be calculated.

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

www.thermofluidprop.com

5. References

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CFC Solutions, Munich	04/2008
RWE IT, Essen	04/2008
Rerum Cognitio, Zwickau	04/2008, 05/2008
ARUP, Berlin	05/2008
Research Center, Karlsruhe	07/2008
AWECO, Neukirch	07/2008
Technical University of Dresden, Professorship of Building Services	07/2008
Technical University of Cottbus, Chair in Power Plant Engineering	07/2008, 10/2008
Ingersoll-Rand, Unicov, Czech Republic	08/2008

Technip Benelux BV, Zoetermeer, Netherlands	08/2008
Fennovoima Oy, Helsinki, Finland	08/2008
Fichtner Consulting & IT, Stuttgart	09/2008
PEU, Espenhain	09/2008
Poyry, Dresden	09/2008
WINGAS, Kassel	09/2008
TUEV Sued, Dresden	10/2008
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	10/2008, 11/2008
AWTEC, Zurich, Switzerland	11/2008
Siemens Power Generation, Erlangen	12/2008

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Audi, Ingolstadt	02/2007
ANO Abfallbehandlung Nord, Bremen	02/2007
TUEV NORD SysTec, Hamburg	02/2007
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Technical University of Dresden, Chair in Jet Propulsion Systems	02/2007
Redacom, Nidau, Switzerland	02/2007
Universität der Bundeswehr, Munich	02/2007
Maxxtec, Sinsheim	03/2007
University of Rostock, Chair in Technical Thermodynamics	03/2007
AGO, Kulmbach	03/2007
University of Stuttgart, Chair in Aviation Propulsions	03/2007
Siemens Power Generation, Duisburg	03/2007
ENTHAL Haustechnik, Rees	05/2007
AWECO, Neukirch	05/2007
ALSTOM, Rugby, Great Britain	06/2007
SAAS, Possendorf	06/2007
Grenzebach BSH, Bad Hersfeld	06/2007
Reichel Engineering, Haan	06/2007
Technical University of Cottbus, Chair in Power Plant Engineering	06/2007
Voith Paper Air Systems, Bayreuth	06/2007
Egger Holzwerkstoffe, Wismar	06/2007
Tissue Europe Technologie, Mannheim	06/2007
Dometic, Siegen	07/2007
RWTH Aachen University, Institute for Electrophysics	09/2007
National Energy Technology Laboratory, Pittsburg, USA	10/2007
Energieversorgung Halle	10/2007
AL-KO, Jettingen	10/2007
Grenzebach BSH, Bad Hersfeld	10/2007

Wiesbaden University of Applied Sciences, Department of Engineering Sciences	10/2007
Endress+Hauser Messtechnik, Hannover	11/2007
Munich University of Applied Sciences, Department of Mechanical Engineering	11/2007
Rerum Cognitio, Zwickau	12/2007
Siemens Power Generation, Erlangen	11/2007
University of Rostock, Chair in Technical Thermodynamics	11/2007, 12/2007

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STORA ENSO Sachsen, Eilenburg	01/2006
Technical University of Munich, Chair in Energy Systems	01/2006
NUTEC Engineering, Bisikon, Switzerland	01/2006, 04/2006
Conwel eco, Bochov, Czech Republic	01/2006
Offenburg University of Applied Sciences	01/2006
KOCH Transporttechnik, Wadgassen	01/2006
BEG Bremerhavener Entsorgungsgesellschaft	02/2006
Deggendorf University of Applied Sciences, Department of Mechanical Engineering and Mechatronics	02/2006
University of Stuttgart, Department of Thermal Fluid Flow Engines	02/2006
Technical University of Munich, Chair in Apparatus and Plant Engineering	02/2006
Energietechnik Leipzig (company license),	02/2006
Siemens Power Generation, Erlangen	02/2006, 03/2006
RWE Power, Essen	03/2006
WAETAS, Pobershau	04/2006
Siemens Power Generation, Goerlitz	04/2006
Technical University of Braunschweig, Department of Thermodynamics	04/2006
EnviCon & Plant Engineering, Nuremberg	04/2006
Brassel Engineering, Dresden	05/2006
University of Halle-Merseburg, Department of USET Merseburg incorporated society	05/2006
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	05/2006
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	05/2006
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M&M Turbine Technology, Bielefeld	06/2006
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ThyssenKrupp Marine Systems, Kiel	07/2006

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Konstanz University of Applied Sciences, Course of Studies Construction and Development	10/2006
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Hannover University of Applied Sciences, Department of Mechanical Engineering	10/2006
Siemens Power Generation, Berlin	11/2006
Zikesch Armaturentechnik, Essen	11/2006
Wismar University of Applied Sciences, Seafaring Department	11/2006
BASF, Schwarzheide	12/2006
Enertech Energie und Technik, Radebeul	12/2006

2005

TUEV Nord, Hannover	01/2005
J.H.K Plant Engineering and Service, Bremerhaven	01/2005
Electrowatt-EKONO, Zurich, Switzerland	01/2005
FCIT, Stuttgart	01/2005
Energietechnik Leipzig (company license)	02/2005, 04/2005 07/2005
eta Energieberatung, Pfaffenhofen	02/2005
FZR Forschungszentrum, Rossendorf/Dresden	04/2005
University of Saarbruecken	04/2005
Technical University of Dresden Professorship of Thermic Energy Machines and Plants	04/2005
Grenzebach BSH, Bad Hersfeld	04/2005
TUEV Nord, Hamburg	04/2005
Technical University of Dresden, Waste Management	05/2005
Siemens Power Generation, Goerlitz	05/2005
Duesseldorf University of Applied Sciences, Department of Mechanical Engineering and Process Engineering	05/2005
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Dumas Verfahrenstechnik, Hofheim	06/2005
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Stadtwerke Leipzig	07/2005
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Basel University of Applied Sciences, Department of Mechanical Engineering, Switzerland	10/2005

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Visteon, Kerpen	03/2004, 10/2004
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HEW-Kraftwerk, Tiefstack	06/2004
h s energieanlagen, Freising	07/2004
FCIT, Stuttgart	08/2004
Physikalisch Technische Bundesanstalt (PTB), Braunschweig	08/2004
Mainova Frankfurt	08/2004
Rietschle Energieplaner, Winterthur, Switzerland	08/2004
MAN Turbo Machines, Oberhausen	09/2004
TUEV Sued, Dresden	10/2004
STEAG Kraftwerk, Herne	10/2004, 12/2004
University of Weimar	10/2004
energeticals (e-concept), Munich	11/2004
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Enertech EUT, Radebeul (company license)	11/2004
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Freudenberg Service, Weinheim	12/2004

2003

Paper Factory, Utzenstorf, Switzerland	01/2003
MAB Plant Engineering, Vienna, Austria	01/2003

Wulff Energy Systems, Husum	01/2003
Technip Benelux BV, Zoetermeer, Netherlands	01/2003
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Rietschle Energieplaner, Winterthur, Switzerland	02/2003
DLR, Leupholdhausen	04/2003
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ENERKO, Aldenhoven	08/2003
STEAG RKB, Leuna	08/2003
eta Energieberatung, Pfaffenhofen	08/2003
exergie, Dresden	09/2003
AWTEC, Zurich, Switzerland	09/2003
Energie, Timelkam, Austria	09/2003
Electrowatt-EKONO, Zurich, Switzerland	09/2003
LG, Annaberg-Buchholz	10/2003
FZR Forschungszentrum, Rossendorf/Dresden	10/2003
EnviCon & Plant Engineering, Nuremberg	11/2003
Visteon, Kerpen	11/2003
VEO Vulkan Energiewirtschaft Oderbruecke, Eisenhuettenstadt	11/2003
Stadtwerke Hannover	11/2003
SaarEnergie, Saarbruecken	11/2003
Fraunhofer-Gesellschaft, Munich	12/2003
Erfurt University of Applied Sciences, Department of Supply Engineering	12/2003
SorTech, Freiburg	12/2003
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M&M Turbine Technology, Bielefeld	01/2001, 09/2001
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Technical University of Graz, Department of Thermal Engineering, Austria	11/1999
Ostendorf Engineering, Gummersbach	12/1999

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SCA Hygiene Products, Munich	10/1998
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