



**Property Library for  
Tetradecamethyl-  
hexasiloxane (MD4M)  
 $\text{C}_{14}\text{H}_{42}\text{O}_5\text{Si}_6$**

**FluidLAB  
with LibMD4M  
for MATLAB®**

Prof. Hans-Joachim Kretzschmar

Dr. Sebastian Herrmann

Dr. Matthias Kunick

**Property Library for the Calculation  
of Tetradecamethylhexasiloxane (MD4M)  
FluidLAB for MATLAB®  
LibMD4M**

## **Contents**

- 0. Package Contents
- 1. Property Functions
  - 1.1 Calculation Programs
  - 1.2 p,v Diagram
  - 1.3 h,s Diagram
  - 1.4 T,s Diagram
- 2. Application of FluidLAB in MATLAB®
  - 2.1 Installing FluidLAB including LibMD4M
  - 2.2 Example: Calculation of  $h = f(p, t, x)$  in an M-File
  - 2.3 Example: Calculation of  $h = f(p, t, x)$  in the Command Window
  - 2.4 Removing FluidLAB including LibMD4M
- 3. Program Documentation
- 4. Property Libraries for Calculating Heat Cycles, Boilers, Turbines, and Refrigerators
- 5. References
- 6. Satisfied Customers

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Professor Hans-Joachim Kretzschmar  
Wallotstr. 3, 01307 Dresden, Germany  
Phone: +49-351-27597860  
Mobile: +49-172-7914607  
Fax: +49-3222-4262250  
Email: [info@thermofluidprop.com](mailto:info@thermofluidprop.com)  
Internet: [www.thermofluidprop.com](http://www.thermofluidprop.com)

## 0. Package Contents

**Zip-file "CD\_FluidLAB\_LibMD4M.zip" including the following files:**

- |                            |  |
|----------------------------|--|
| FluidLAB_LibMD4M_Setup.exe | - Installation program for the FluidLAB Add-On<br>for use in MATLAB® |
| LibMD4M.dll                | - DLL with functions of the LibMD4M library                          |

### Documentation

- |                               |                |
|-------------------------------|----------------|
| FluidLAB_LibMD4M_Docu_Eng.pdf | - User's Guide |
|-------------------------------|----------------|

# 1. Property Functions

## 1.1 Calculation Programs

“MD4M” means Tetradecamethylhexasiloxane (C<sub>14</sub>H<sub>42</sub>O<sub>5</sub>Si<sub>6</sub>)

Functional Dependence	Function Name	Call from Fortran program	Call in DLL LibMD4M as parameter	Property or Function	Unit of the result
$c_p = f(p, t, x)$	cp_ptx_MD4M	CPPTXMD4M(P,T,X)	C_CPPTXMD4M(CP,P,T,X)	Specific isobaric heat capacity	kJ/(kg K)
$c_v = f(p, t, x)$	cv_ptx_MD4M	CVPTXMD4M(P,T,X)	C_CVPTXMD4M(CV,P,T,X)	Specific isochoric heat capacity	kJ/(kg K)
$\left(\frac{\partial p}{\partial T}\right)_v = f(p, t, x)$	dpdvt_ptx_MD4M	DPDTVMD4M(P,T,X)	C_DPDVTMD4M(DPDT,P,T,X)	Derivative of pressure with respect to temperature (at constant specific volume)	kPa/K
$\left(\frac{\partial p}{\partial v}\right)_T = f(p, t, x)$	dpdvt_ptx_MD4M	DPDVTMD4M(P,T,X)	C_DPDVTMD4M(DPDV,P,T,X)	Derivative of pressure with respect to specific volume (at constant temperature)	kPa/(m <sup>3</sup> /kg)
$h = f(p, t, x)$	h_ptx_MD4M	HPTXMD4M(P,T,X)	C_HPTXMD4M(H,P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p, t, x)$	kappa_ptx_MD4M	KAPPAPTXMD4M(P,T,X)	C_KAPPAPTXMD4M(KAPPA,P,T,X)	Isentropic exponent	-
$p_s = f(t)$	ps_t_MD4M	PSTMD4M(T)	C_PSTMD4M(PS,T)	Vapor pressure from temperature	bar
$\rho = f(p, t, x)$	rho_ptx_MD4M	RHOPTXMD4M(P,T,X)	C_RHOPTXMD4M(RHO,P,T,X)	Density	kg/m <sup>3</sup>
$s = f(p, t, x)$	s_ptx_MD4M	SPTXMD4M(P,T,X)	C_SPTXMD4M(S,P,T,X)	Specific entropy	kJ/(kg K)
$t = f(p, h)$	t_ph_MD4M	TPHMD4M(P,H)	C_TPHMD4M(T,P,H)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p, s)$	t_ps_MD4M	TPSMD4M(P,S)	C_TPSMD4M(T,P,S)	Backward function: Temperature from pressure and entropy	°C
$t_s = f(p)$	ts_p_MD4M	TSPMD4M(P)	C_TSPMD4M(TS,P)	Saturation temperature from pressure	°C
$u = f(p, t, x)$	u_ptx_MD4M	UPTXMD4M(P,T,X)	C_UPTXMD4M(U,P,T,X)	Specific internal energy	kJ/kg
$v = f(p, t, x)$	v_ptx_MD4M	VPTXMD4M(P,T,X)	C_VPTXMD4M(V,P,T,X)	Specific volume	m <sup>3</sup> /kg
$w = f(p, t, x)$	w_ptx_MD4M	WPTXMD4M(P,T,X)	C_WPTXMD4M(W,P,T,X)	Isentropic speed of sound	m/s
$x = f(p, h)$	x_ph_MD4M	XPHMD4M(P,H)	C_XPHMD4M(X,P,H)	Backward function: Vapor fraction from pressure and enthalpy	kg/kg

Functional Dependence	Function Name	Call from Fortran program	Call in DLL LibMD4M as parameter	Property or Function	Unit of the result
$x = f(p, s)$	x_ps_MD4M	XPSMD4M(P,S)	C_XPSMD4M(X,P,S)	Backward function: Vapor fraction from pressure and entropy	kg/kg
$Z = f(p, t, x)$	Z_ptx_MD4M	ZPTXMD4M(P,T,X)	C_ZPTXMD4M(W,P,T,X)	Compression factor	-

**Units:**

$t$  in °C  
 $p$  in bar  
 $x$  in (kg of saturated steam)/(kg wet steam)

#### Range of validity

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $399.85^\circ\text{C}$   
Pressure range: from  $p = 0.00001$  bar to 300 bar

#### Reference state

$h = 0$  kJ/kg and  $s = 0$  kJ/(kg K) at  $t_B = 259.573^\circ\text{C}$  on the boiling curve ( $x = 0$ ;  $p_s = p_N = 1.01325$  bar)

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

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

#### Single-phase region

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

#### Wet-steam region

If the state point to be calculated is located in the wet steam region, a value for  $x$  between 0 and 1 ( $x = 0$  for saturated liquid,  $x = 1$  for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for  $x$ . When calculating wet steam either the given value for  $t$  and  $p = -1000$  or the given value for  $p$  and  $t = -1000$  and in both cases the value for  $x$  between 0 and 1 must be entered.

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

Wet steam region: Temperature range from  $t = 26.85\text{ °C}$  to  $t_c = 379.05\text{ °C}$

Pressure range from  $p_s(26.85\text{ °C}) = 0.00001093377\text{ bar}$  to  $p_c = 8.7747391\text{ bar}$

#### **Note.**

*If the calculation results in  $-1000$ , the values entered represent a state point beyond the range of validity of MD4M. For further information on each function and its range of validity see Chapter 3. The same information may also be accessed via the online help pages.*

## 2 Application of FluidLAB in MATLAB®

The FluidLAB Add-In has been developed to calculate thermodynamic properties in MATLAB® more conveniently. Within MATLAB® it enables the direct call of functions relating to Tetradecamethylhexasiloxane from the LibMD4M property library.

### 2.1 Installing FluidLAB including LibMD4M

This section describes the installation of FluidLAB including the LibMD4M property library.

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\_LibMD4M.zip", you will see the folder

CD\_FluidLAB\_LibMD4M

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 three files:

FluidLAB\_LibMD4M\_Docu\_Eng.pdf

FluidLAB\_LibMD4M\_Setup.exe

LibMD4M.dll.

In order to run the installation of FluidLAB including the LibMD4M property library, double-click on the file

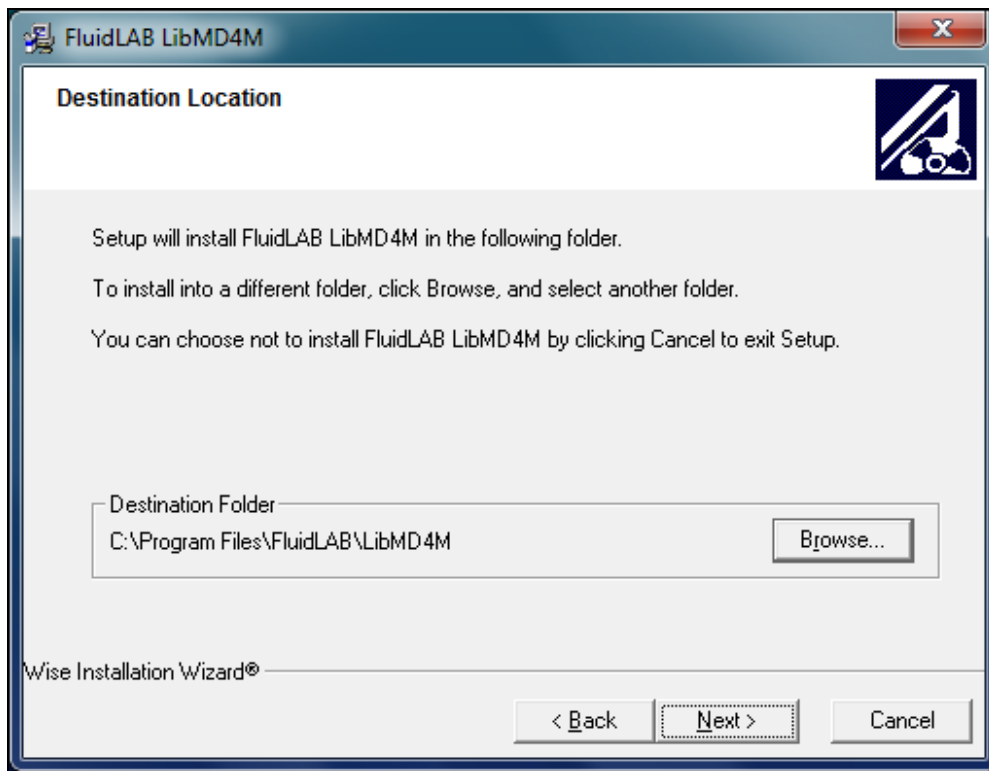
FluidLAB\_LibMD4M\_Setup.exe.

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\LibMD4M

By clicking the "Browse..." button, you can change the installation directory before installation (see figure below).



**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" pops up. 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 for LibMD4M into the directory "C:\Program Files\FluidLAB\LibMD4M":

advapi32.dll	LibMD4M.dll
Dformd.dll	msvc60.dll
Dforrt.dll	msvcrt.dll
INSTALL.LOG	Unwise.exe
LC.dll	Unwise.ini

- MATLAB®-Interface-Program for calculable functions

cp_ptx_MD4M	t_ph_MD4M
cv_ptx_MD4M	t_ps_MD4M
dpdtv_ptx_MD4M	ts_p_MD4M
dpdvt_ptx_MD4M	u_ptx_MD4M
h_ptx_MD4M	v_ptx_MD4M
Kappa_ptx_MD4M	w_ptx_MD4M
ps_t_MD4M	x_ph_MD4M
rho_ptx_MD4M	x_ps_MD4M
s_ptx_MD4M	Z_ptx_MD4M

Now, you have to overwrite the file "LibMD4M.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 "LibMD4M.dll" in order to highlight it.

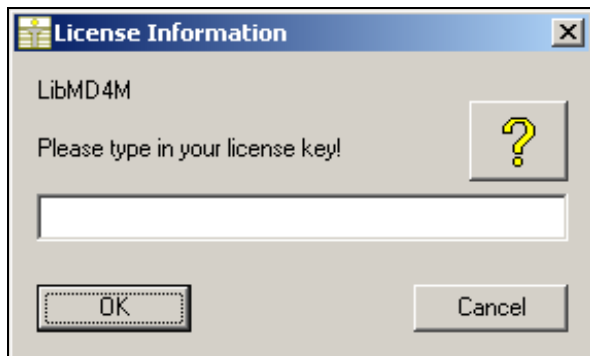
Then click on the "Edit" menu in your Explorer and select "Copy".

Now, open your FluidLAB directory (the standard being C:\Program Files\FluidLAB\LibMD4M) and insert the file "LibMD4M.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 "LibMD4M.dll" successfully and the property functions are available in MATLAB®.

## Licensing the LibMD4M 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 LibMD4M (see figure below).



**Figure 2.2:** "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 2.3:** "Help" window

If you do not enter a valid license it is still possible to use MATLAB® by clicking "Cancel". In this case, the LibMD4M property library will display the result "-11111111" for every calculation.

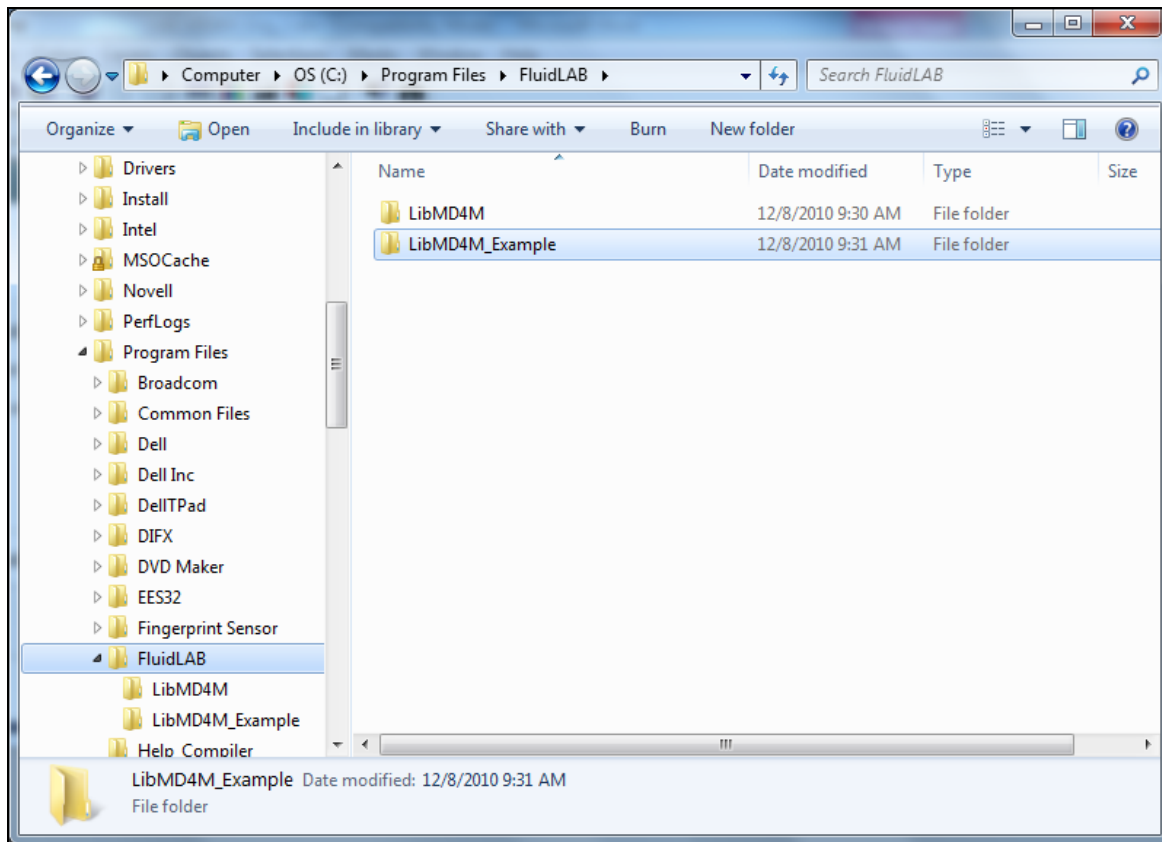
The "License Information" window will appear every time you use FluidLAB LibMD4M until you enter a license code to complete registration. If you decide not to use FluidLAB LibMD4M, you can uninstall the program following the instructions given in section 2.4 of this User's Guide.

## 2.2 Example: Calculation of $h = f(p, t, x)$ in an M-File

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

Please carry out the following instructions:

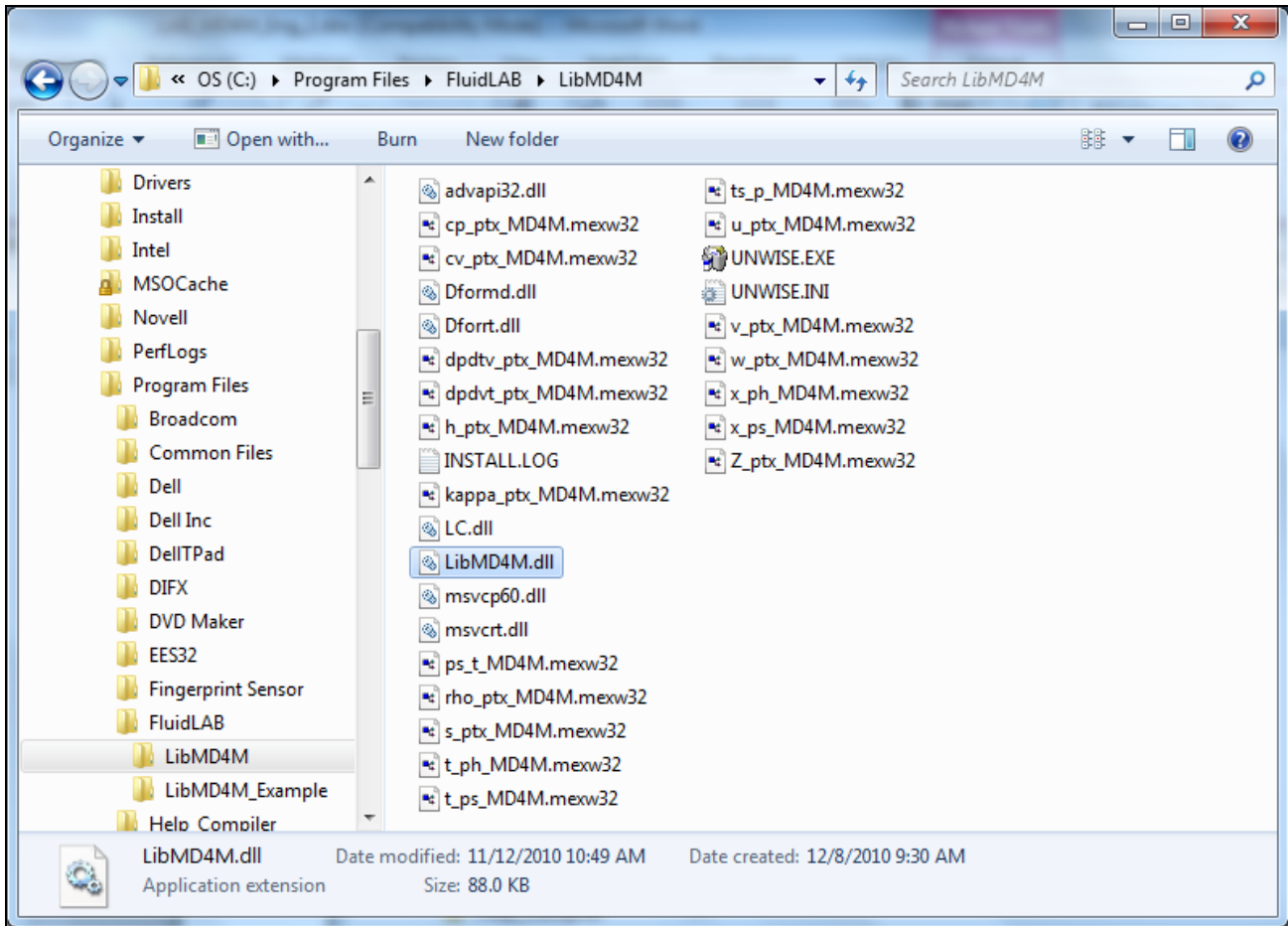
- Start Windows Explorer®, Total Commander®, My Computer or another file manager program. The following description refers to Windows Explorer®.
- Your Windows Explorer® should be set to "Details" for easier viewing. Click the "Views" button and select "Details."
- Switch into the program directory of FluidLAB, in which you will find the folder "LibMD4M"; it is generally saved under: "C:\Program Files\FluidLAB"
- Create the folder "LibMD4M\_Example" by clicking on "File" in the Explorer® menu, then "New" in the menu which appears and afterwards selecting "Folder". Name the new folder "LibMD4M\_Example."
- You will now see the following window:



**Figure 2.4:** Folders "LibMD4M" and "LibMD4M\_Example"

- Switch into the directory "LibMD4M" within "FluidLAB", the standard being "C:\Program Files\FluidLAB\LibMD4M."

- You will see the following window:

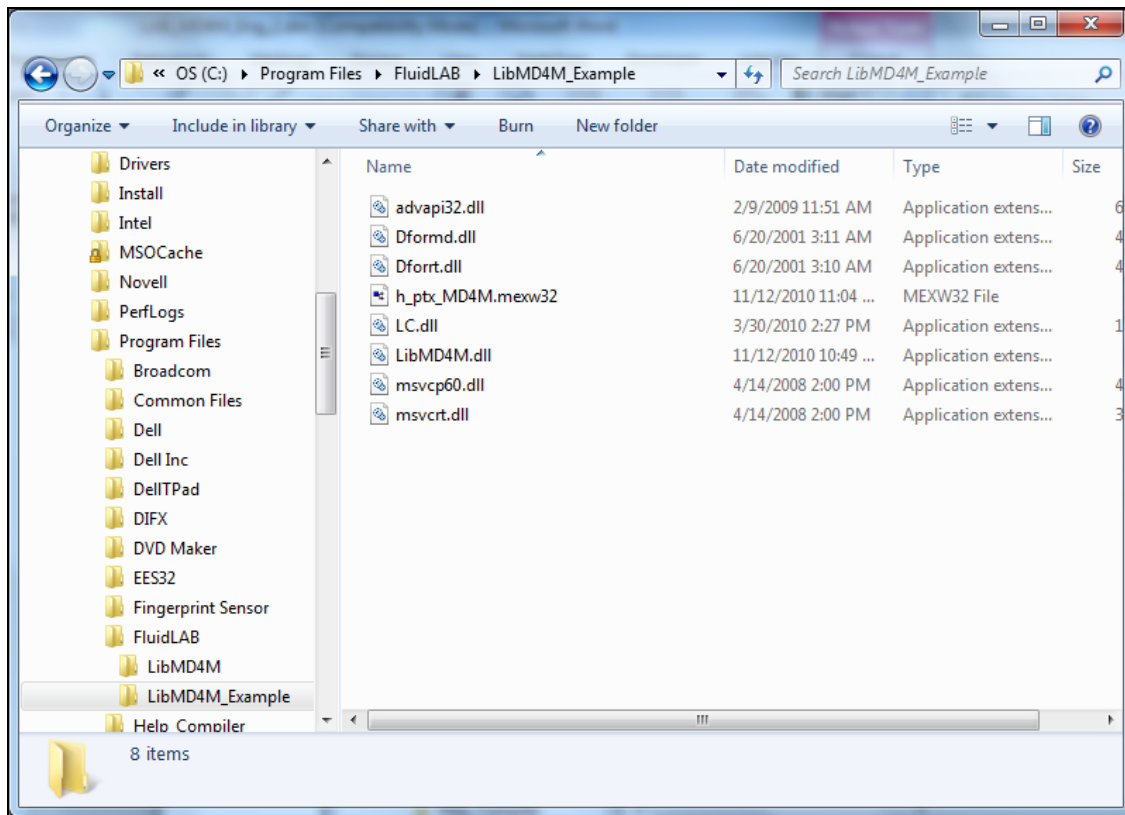


**Figure 2.5:** Contents of the folder "LibMD4M"

You will now have to copy the following files into the directory "C:\Program Files\FluidLAB\LibMD4M\_Example" in order to calculate the function  $h = f(p, t, x)$ .

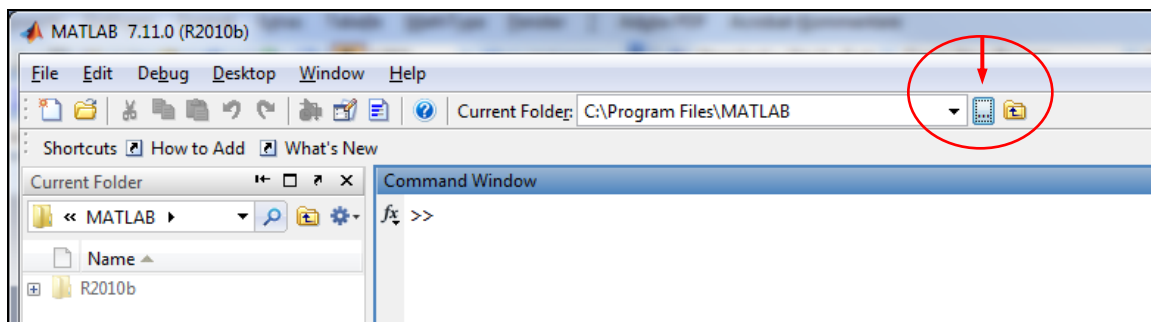
- The following eight files are needed:
  - "advapi32.dll"
  - "Dformd.dll"
  - "Dforrt.dll"
  - "h\_ptx\_MD4M.mexw32"
  - "LC.dll"
  - "LibMD4M.dll"
  - "msvc60.dll"
  - "msvcrt.dll."
- Click the file "h\_ptx\_MD4M.mexw32", then click "Edit" in the upper menu bar and select "Copy".
- Switch into the directory "C:\Program Files\FluidLAB\LibMD4M\_Example", 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:



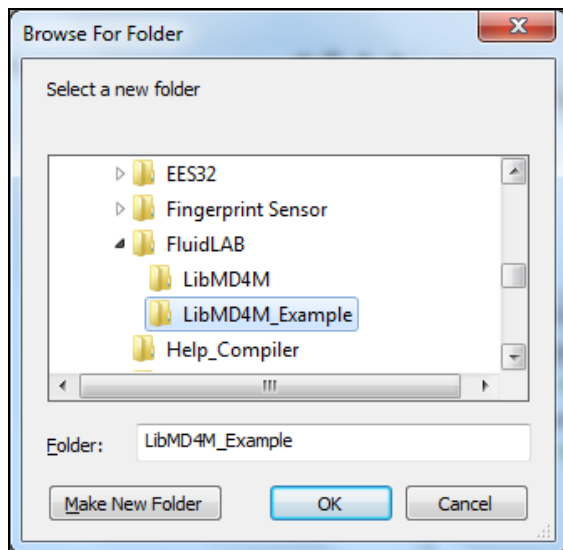
**Figure 2.6:** Contents of the folder "LibMD4M\_Example"

- Start MATLAB® (if you have not started it before).
- Click the button marked in the next figure in order to open the folder "\LibMD4M\_Example" in the "Current Folder" window.



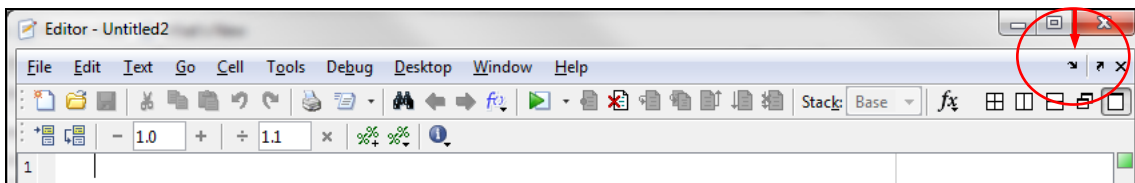
**Figure 2.7:** Selection of the working directory

- Find and select the directory "C:\Program Files\FluidLAB\LibMD4M\_Example" in the pop-up menu (see the following image).



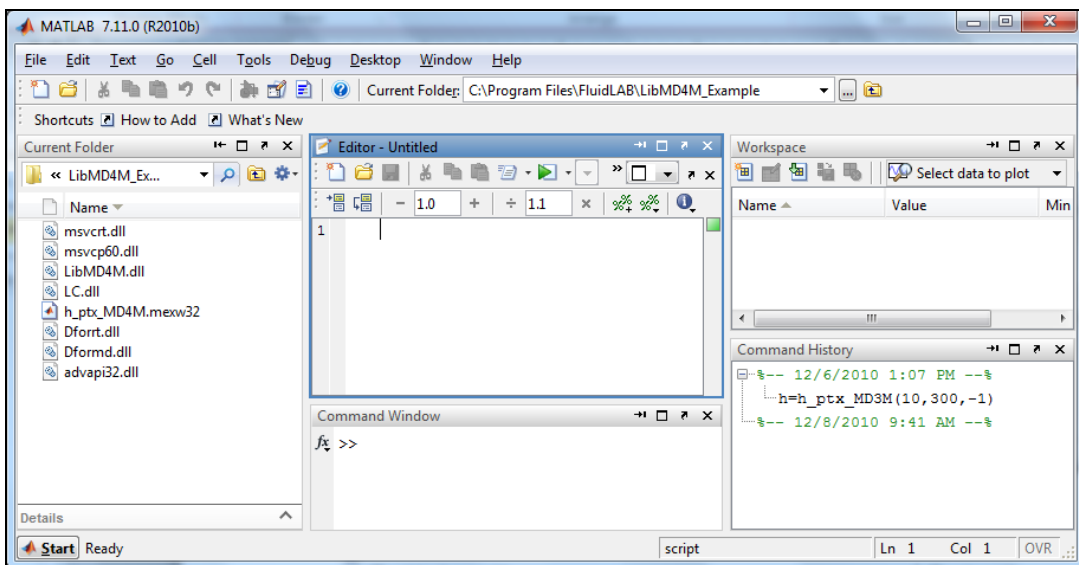
**Figure 2.8:** Choosing the "LibMD4M\_Example" folder

- Confirm your selection by clicking the "OK" button.
- First of all you need to create an M-File in MATLAB®. Within MATLAB® click "Desktop", then select "Editor". Now click on the "New Script" button in the Editor Window.
- 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 2.9:** Embedding the "Editor" window

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



**Figure 2.10:** Embedded "Editor" window

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

Text to be written:	Explanation:
<code>% h_ptx_MD4M.m</code>	file name as comment
<code>%%</code>	paragraph separation
<code>p=10; % pressure in bar</code>	declaration of the
<code>t=300; % temperature in °C</code>	variables pressure,
<code>x=-1; % vapor fraction in kg/kg</code>	temperature, art and
<code>%%</code>	composition of mixture
<code>h=h_ptx_MD4M(p,t,x)</code>	paragraph separation
<code>%%</code>	function call
<code>%%</code>	paragraph separation

- Remarks:

- The program interprets the first line, starting with "%," to be a data description in "Current Directory."
- Paragraph separations which are mandatory are marked with "%%". This also serves to separate the declaration of variables and calculation instructions.
- The words which are printed in green, start with "%" and come after the variables are comments. They are not in fact absolutely necessary, but they are very helpful for your overview and to make the process more easily understood.
- Omit the semicolons after the numerical values if you wish to see the result for  $h$  and the input parameters.

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

- **First operand: Value for  $p = 10$**   
(Range of validity:  $p = 0.00001 \text{ bar}$  to  $300 \text{ bar}$ )
- **Second operand: Value for  $t = 300 \text{ °C}$**   
(Range of validity:  $t = 26.85 \text{ °C}$  to  $399.85 \text{ °C}$ )
- **Third operand: Value for  $x = -1 \text{ kg/kg}$**

#### 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  $p = -1000$  or the given value for  $p$  and  $t = -1000$  and in both cases the value for  $x$  between 0 and 1 must be entered.

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

(MD4M Saturation pressure curve:

$$t = 26.85 \text{ °C} \text{ to } t_c = 379.05 \text{ °C}$$

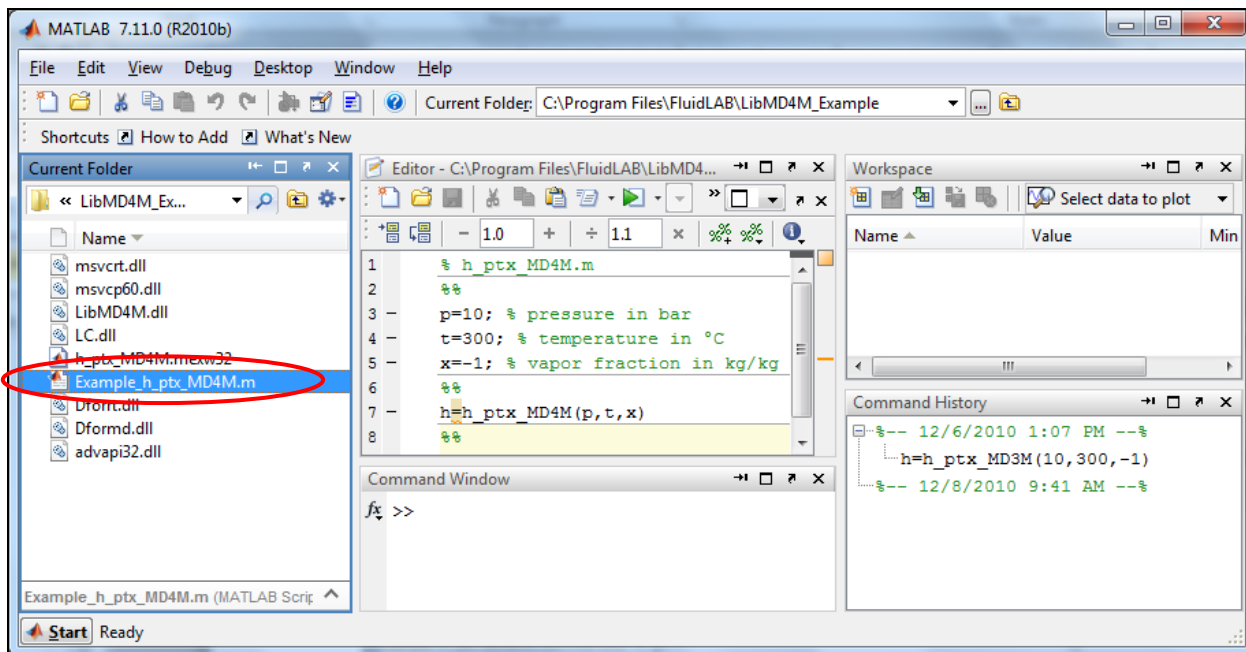
$$p_S(26.85\text{ }^{\circ}\text{C}) = 0.00001093377\text{ bar to }p_C = 8.7747391\text{ bar})$$

- 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 "LibMD4M\_Example" must be displayed in the "Save in:" field.
- Next to "File name" you have to type "Example\_h\_ptx\_MD4M.m" and afterwards click the "Save" button.

**Note.**

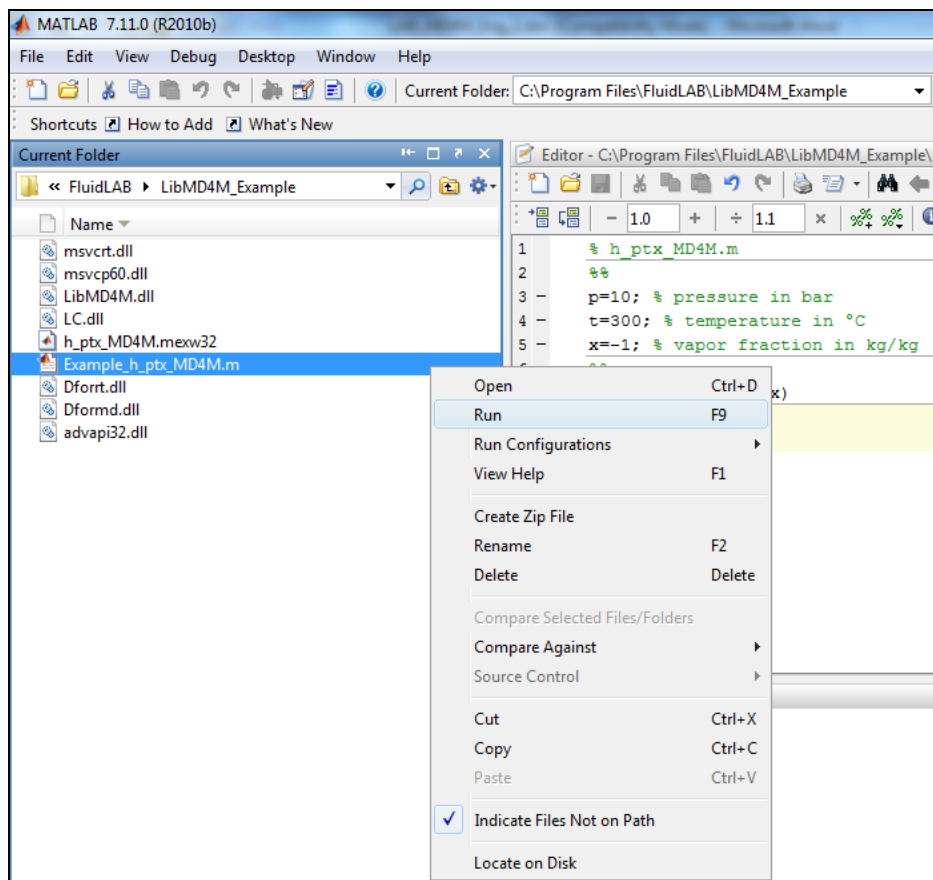
The name of the example file has to be different in comparison to the name of the used function. For example, the file could not be named "h\_ptx\_MD4M.m" in this case. Otherwise an error message will appear during the calculation.

- You will now see the following window:



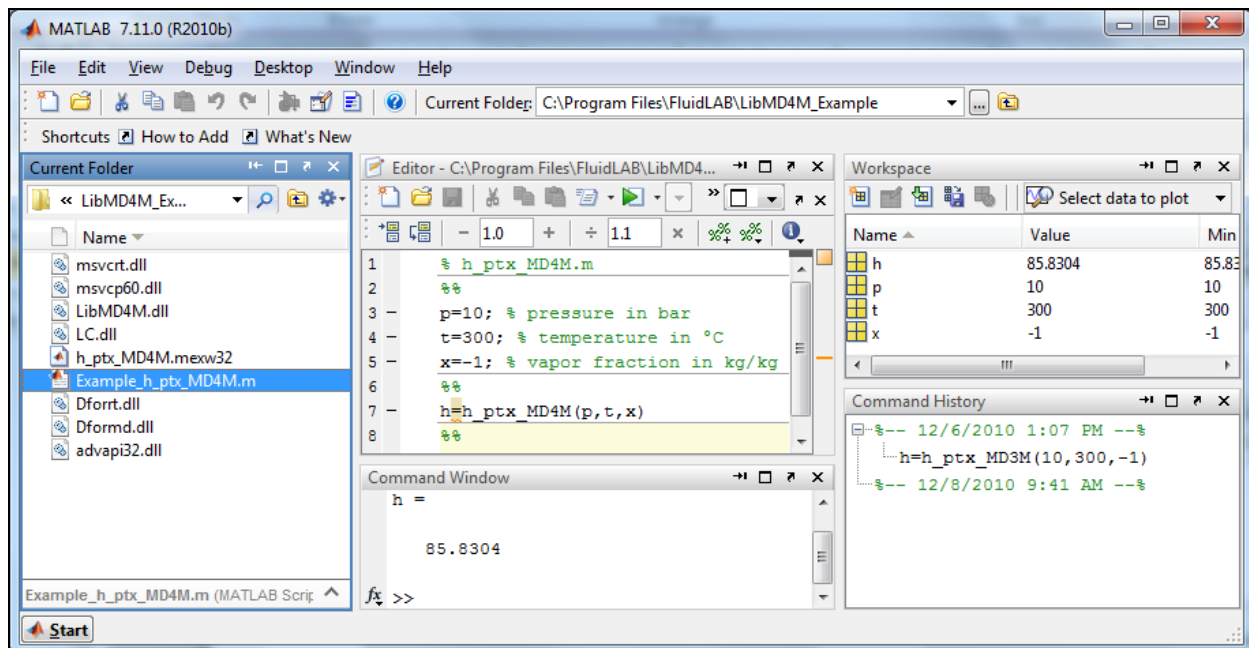
**Figure 2.11:** "Example\_h\_ptx\_MD4M.m" M-file

- Within the "Current Folder" window, the file "Example\_h\_ptx\_MD4M.m" appears.
- Right-click on this file and select "Run" in the menu which appears (see next image).



**Figure 2.12:** Running the "Example\_h\_ptx\_MD4M.m" M-file

- You will see the following window:



**Figure 2.13:** MATLAB® with calculated result

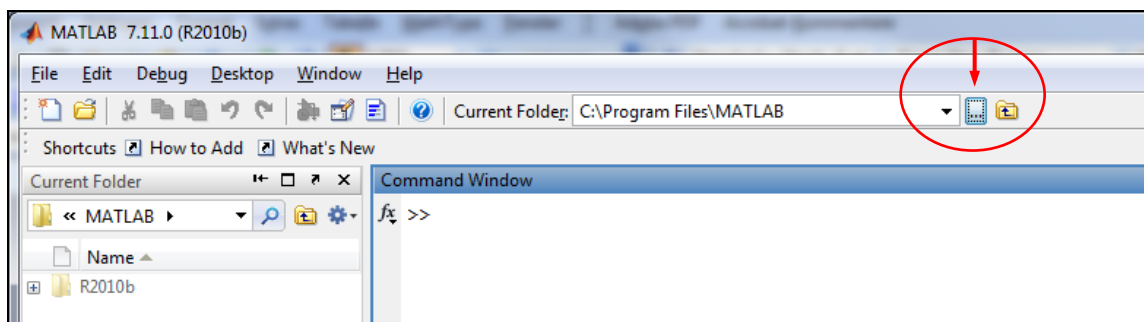
The result for  $h$  appears in the "Command Window".

⇒ The result in our sample calculation here is: " $h = 85.8304$ ". 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 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\LibMD4M\_Example," and you may use it as a basis for further calculations using FluidLAB.

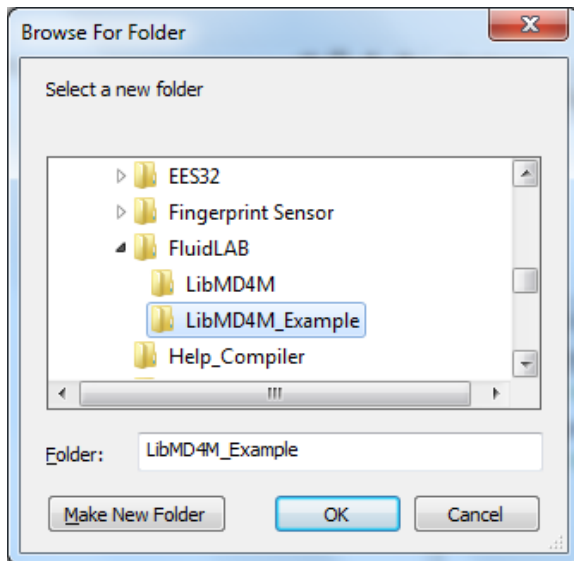
### 2.3 Example: Calculation of $h = f(p, t, x)$ in the Command Window

- Start MATLAB® (if you have not started it already).
- Click the button marked in the following image in order to open the folder "\LibMD4M\_Example" in the window "Current Folder."



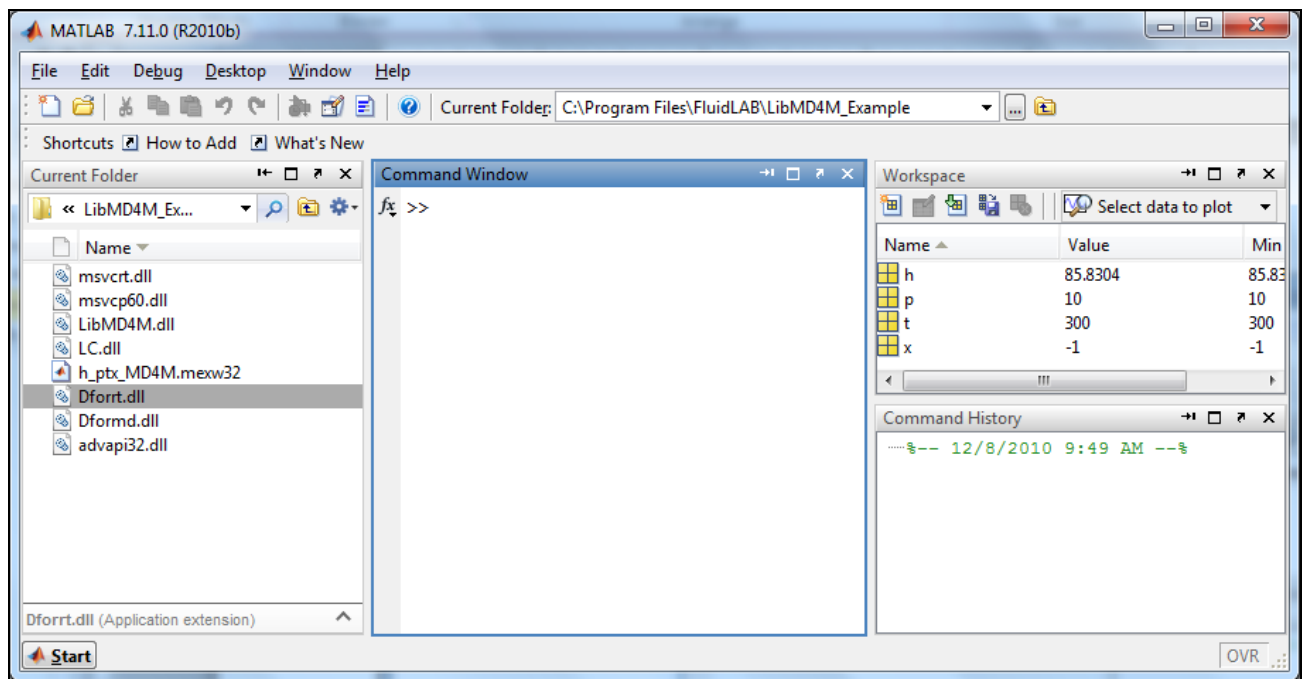
**Figure 2.14:** Selection of the working directory

- Find and select the directory "C:\Program Files\FluidLAB\LibMD4M\_Example" in the pop-up menu (see the following image).



**Figure 2.15:** Choosing the "LibMD4M\_Example" folder

- Confirm your selection by clicking the "OK" button.
- You will see the following window:



**Figure 2.16:** MATLAB® with necessary files

Corresponding to the table of the property functions in Chapter 1 you have to call up the function "**h\_ptx\_MD4M**" as follows for calculating  $h = f(p, t, x)$ .

Write "**h=h\_ptx\_MD4M(10,300,-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:  $p = 0.00001$  bar to 300 bar)
- **Second operand: Value for  $t = 300$  °C**  
(Range of validity:  $t = 26.85$  °C to 399.85 °C)
- **Third operand: Value for  $x = -1$**

#### 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  $p = -1000$  or the given value for  $p$  and  $t = -1000$  and in both cases the value for  $x$  between 0 and 1 must be entered.

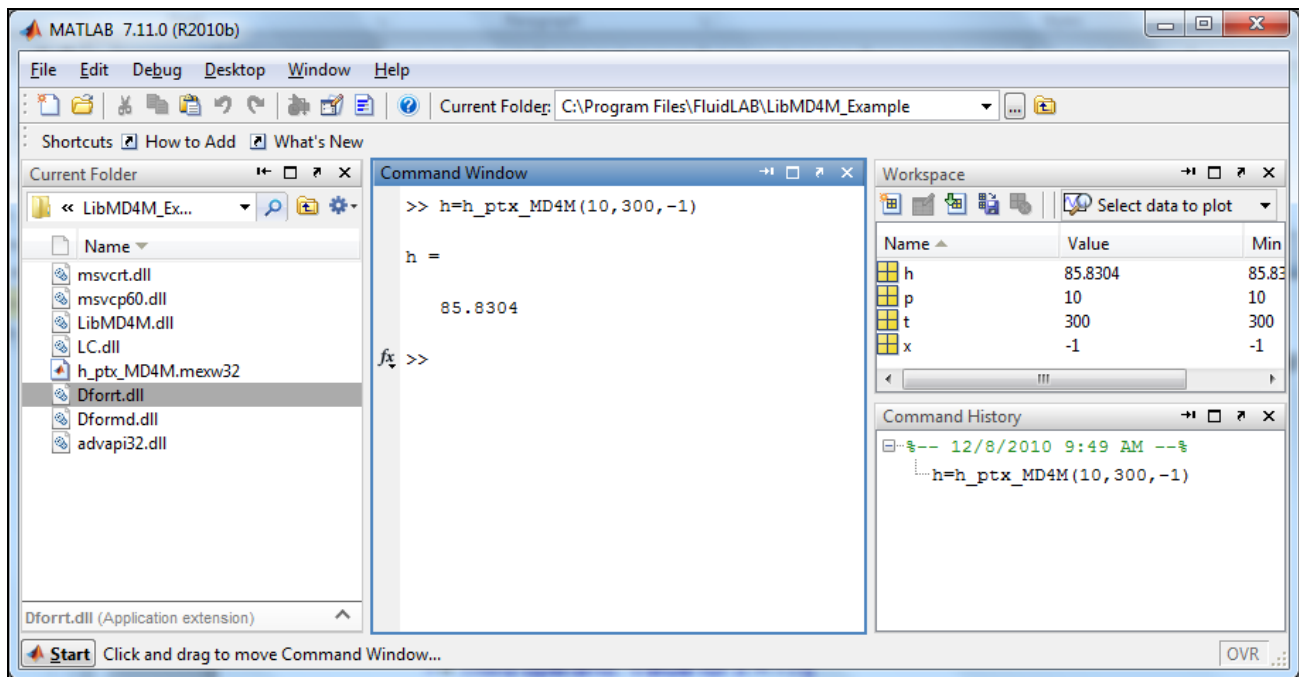
If  $p$  and  $t$  and  $x$  are entered as given values, the program considers  $p$  and  $t$  to be appropriate to represent the vapor pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in  $-1000$ .

(MD4M Saturation pressure curve:

$$t = 26.85 \text{ °C to } t_c = 379.05 \text{ °C}$$

$$p_s(26.85 \text{ °C}) = 0.00001093377 \text{ bar to } p_c = 8.7747391 \text{ bar})$$

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



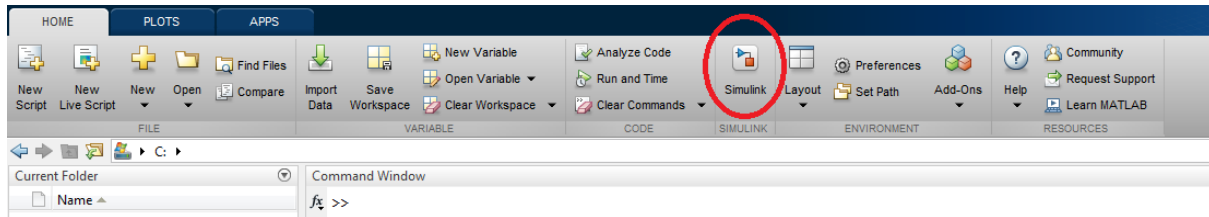
**Figure 2.17:** MATLAB® with calculated result

⇒ In the "Command Window" you will see the result " $h = 85.8304$ ". 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 files into the working directory as well, because MATLAB® can only access functions that are located in the "Current Directory" window.

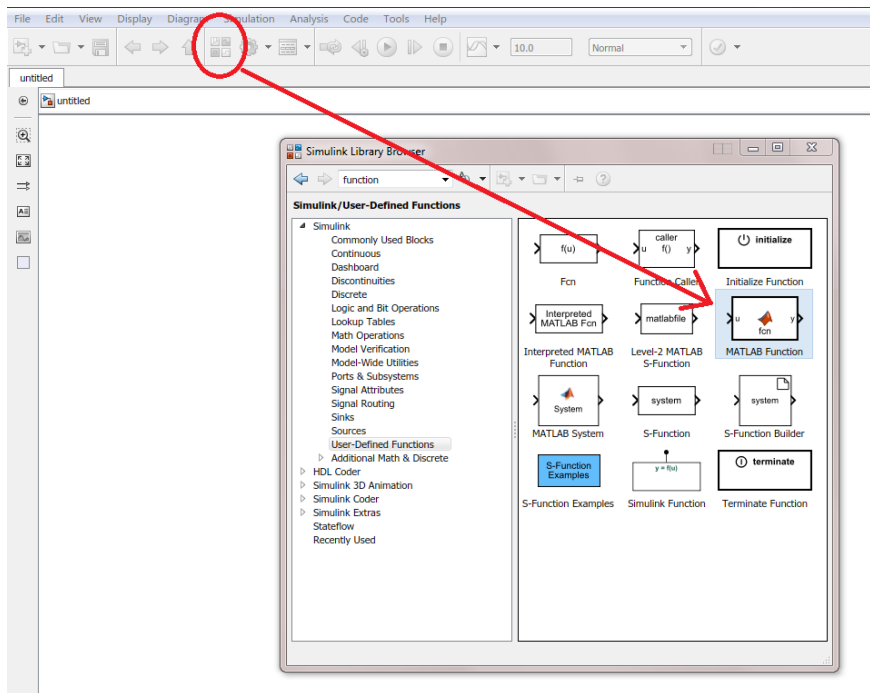
## 2.4 Using FluidLAB with SIMULINK

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.



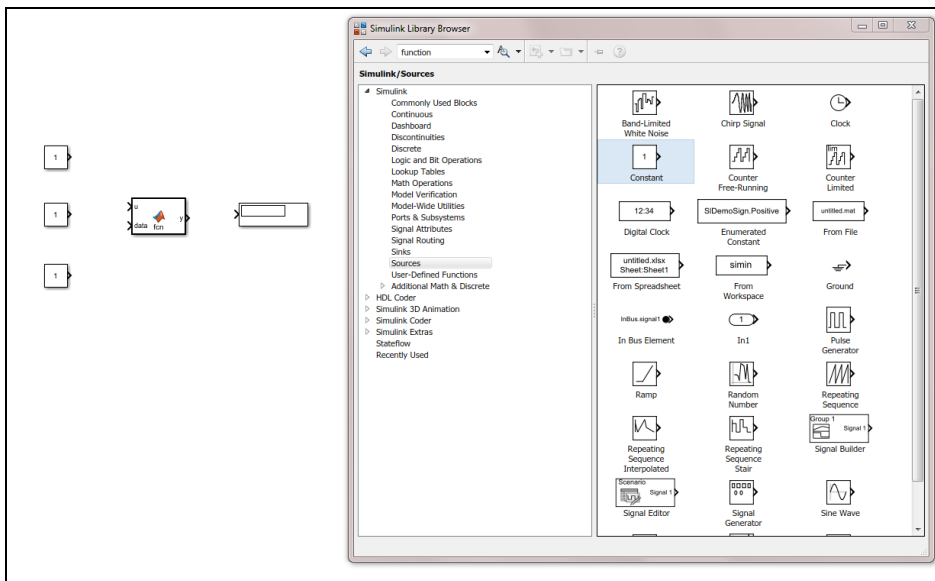
**Figure 2.18:** Starting Simulink

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 2.19.



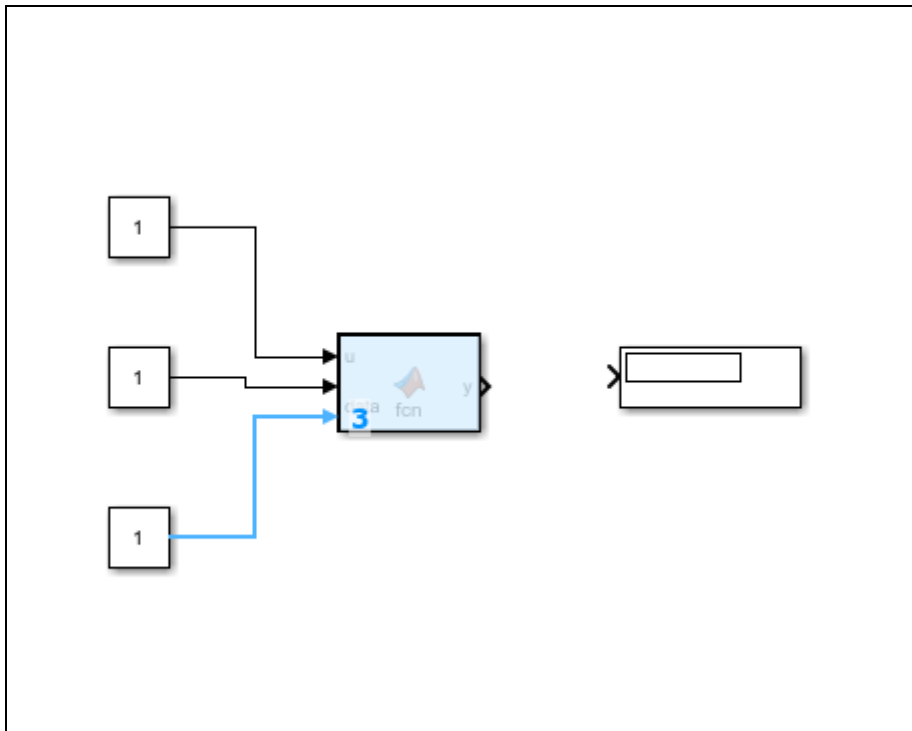
**Figure 2.19:** Simulink library browser and choosing a MATLAB Function

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 2.20:** 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 2.21:** 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 2.2 and 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)
```

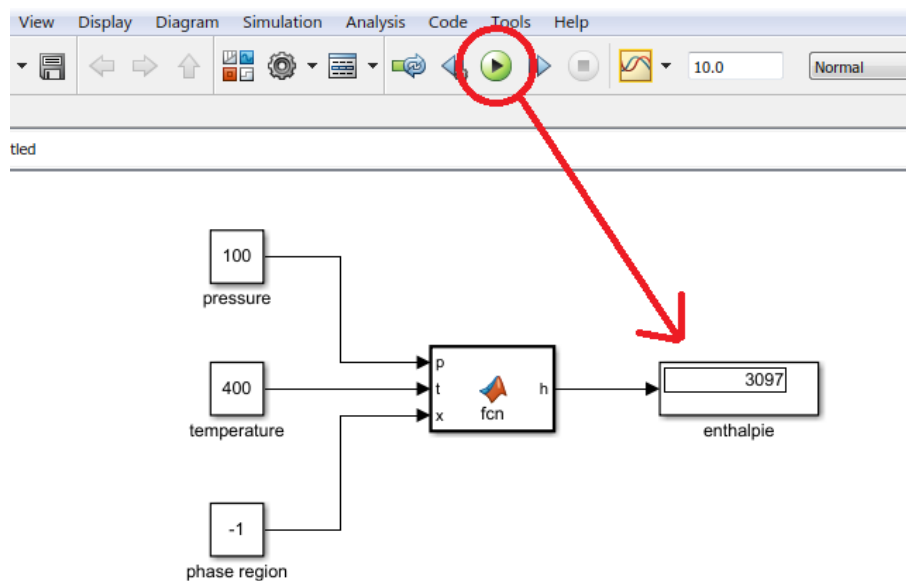
```

coder.extrinsic('addpath');
coder.extrinsic('h_ptx_MD4M');
addpath('C:\Program Files\FluidLAB\LibMD4M');
h = h_ptx_MD4M(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_MD4M');	Choose the function name of the FluidLAB function
addpath('C:\Program Files\FluidLAB\LibMD4M');	Add the installation path of FluidLAB
h = h_ptx_MD4M(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 2.22:** Starting the simulation and result of the calculation

Your result is may an other than shown in figure 2.22. If you want to calculate the example please use the values from section 2.2 and 2.3.

## 2.5 Removing FluidLAB including LibMD4M

To remove the property library LibMD4M from your hard disk drive in Windows®, click "Start" in the Windows® task bar, select "Settings" and click "Control Panel".

Now double-click on "Add or Remove Programs". In the list box of the "Add or Remove Programs" window that appears select "FluidLAB LibMD4M" 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 LibMD4M installed, the directory "FluidLAB" will be removed as well.

### 3. Program Documentation

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

Function Name: **cp\_ptx\_MD4M**

Subroutine with function value: **REAL\*8 FUNCTION CPPTXMD4M(P,T,X)**  
for call from Fortran **REAL\*8 P,T,X**

Subroutine with parameter: **INTEGER\*4 FUNCTION C\_CPPTXMD4M(CP,P,T,X)**  
for call from DLL **REAL\*8 CP,P,T,X**

### Input Values:

**P** - Pressure  $p$  in bar  
**T** - Temperature  $t$  in °C  
**X** - Vapor fraction  $x$  (kg of saturated steam)/(kg wet steam)

### Result

**CPPTXMD4M, CP** or **cp\_ptx\_MD4M** - specific isobaric heat capacity  $c_p$  in kJ/(kg K)

### Range of validity

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $399.85^\circ\text{C}$   
 Pressure range: from  $p = 0.00001$  bar to 300 bar

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

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

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

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

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for  $t$  and  $p = -1000$ , or the given value for  $p$  and  $t = -1000$ , plus the value for  $x$  ( $x = 0$  or  $x = 1$ ). If  $p$  and  $t$  and  $x$  are entered as given values, the program will consider  $p$  and  $t$  to be appropriate to represent the vapor pressure curve.

Saturated liquid and Temperature ranges from  $t = 26.85^\circ\text{C}$  to  $t_c = 379.05^\circ\text{C}$

saturated vapor line: Pressure ranges from  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  bar

### Results for wrong input values

Result **CPPTXMD4M = -1000, CP = -1000** or **cp\_ptx\_MD4M = -1000** for input values:

Single phase region:  $p > 300$  bar or  $p < 0.00001$  bar or  
 ( $x = -1$ )  $t > 399.85^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

Saturation lines: at  $p = -1000$  and  $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$   
 at  $t = -1000$  and  $p > p_c = 8.7747391$  bar  
 or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar or  
 at  $p > p_c = 8.7747391$  bar or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar and  
 $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

**References:** [1]

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

Function Name: **cv\_ptx\_MD4M**

Subroutine with function value: **REAL\*8 FUNCTION CVPTXMD4M(P,T,X)**  
for call from Fortran **REAL\*8 P,T,X**

Subroutine with parameter: **INTEGER\*4 FUNCTION C\_CVPTXMD4M(CV,P,T,X)**  
for call from DLL **REAL\*8 CV,P,T,X**

### Input Values:

**P** - Pressure  $p$  in bar  
**T** - Temperature  $t$  in °C  
**X** - Vapor fraction  $x$  (kg of saturated steam)/(kg wet steam)

### Result

**CVPTXMD4M, CV** or **cv\_ptx\_MD4M** - specific isochoric heat capacity  $c_v$  in kJ/(kg K)

### Range of validity

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $399.85^\circ\text{C}$   
 Pressure range: from  $p = 0.00001$  bar to 300 bar

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

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

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

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

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for  $t$  and  $p = -1000$ , or the given value for  $p$  and  $t = -1000$ , plus the value for  $x$  ( $x = 0$  or  $x = 1$ ). If  $p$  and  $t$  and  $x$  are entered as given values, the program will consider  $p$  and  $t$  to be appropriate to represent the vapor pressure curve.

Saturated liquid and      Temperature ranges from  $t = 26.85^\circ\text{C}$  to  $t_c = 379.05^\circ\text{C}$

saturated vapor line:      Pressure ranges from  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  bar

### Results for wrong input values

Result **CVPTXMD4M = -1000, CV = -1000** or **cv\_ptx\_MD4M = -1000** for input values:

Single phase region:       $p > 300$  bar or  $p < 0.00001$  bar or  
 ( $x = -1$ )       $t > 399.85^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

Saturation lines:      at  $p = -1000$  and  $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$   
                              at  $t = -1000$  and  $p > p_c = 8.7747391$  bar  
                              or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar or  
                              at  $p > p_c = 8.7747391$  bar or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar and  
                               $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

### References: [1]

**Derivative of Pressure with Respect to Temperature (at Constant Specific Volume)**  $\left(\frac{\partial p}{\partial T}\right)_v = f(p, t, x)$

Function Name: **dpdptv\_ptx\_MD4M**  
 Subroutine with function value: **REAL\*8 FUNCTION DPDTVPTXMD4M(P,T,X)**  
 for call from Fortran **REAL\*8 P,T,X**  
 Subroutine with parameter: **INTEGER\*4 FUNCTION C\_DPDTVPTXMD4M(DPDTV,P,T,X)**  
 for call from DLL **REAL\*8 DPDTV,P,T,X**

**Input Values:**

**P** - Pressure  $p$  in bar  
**T** - Temperature  $t$  in °C  
**X** - Vapor fraction  $x$  (kg of saturated steam)/(kg wet steam)

**Result**

**DPDTVPTXMD4M, DPDTV or dpdptv\_ptx\_MD4M** - Derivative of pressure with respect to temperature (at constant specific volume) dpdptv in kPa/K

**Range of validity**

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $399.85^\circ\text{C}$   
 Pressure range: from  $p = 0.00001$  bar to 300 bar

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

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

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

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

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for  $t$  and  $p = -1000$ , or the given value for  $p$  and  $t = -1000$ , plus the value for  $x$  ( $x = 0$  or  $x = 1$ ). If  $p$  and  $t$  and  $x$  are entered as given values, the program will consider  $p$  and  $t$  to be appropriate to represent the vapor pressure curve.

Saturated liquid and Temperature ranges from  $t = 26.85^\circ\text{C}$  to  $t_c = 379.05^\circ\text{C}$

saturated vapor line: Pressure ranges from  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  bar

**Results for wrong input values**

Result **DPDTVPTXMD4M = -1000, DPDTV = -1000 or dpdptvo\_ptx\_MD4M = -1000** for input values:

Single phase region:  $p > 300$  bar or  $p < 0.00001$  bar or  
 ( $x = -1$ )  $t > 399.85^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

Saturation lines: at  $p = -1000$  and  $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$   
 at  $t = -1000$  and  $p > p_c = 8.7747391$  bar  
 or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar or  
 at  $p > p_c = 8.7747391$  bar or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar and  
 $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

**References:** [1]

**Derivative of Pressure with Respect to Specific Volume (at Constant Temperature)**  $\left(\frac{\partial p}{\partial v}\right)_T = f(p, t, x)$

Function Name: **dpdvt\_ptx\_MD4M**  
 Subroutine with function value: **REAL\*8 FUNCTION DPDVTPTXMD4M(P,T,X)**  
 for call from Fortran **REAL\*8 P,T,X**  
 Subroutine with parameter: **INTEGER\*4 FUNCTION C\_DPDVTPTXMD4M(DPDVT,P,T,X)**  
 for call from DLL **REAL\*8 DPDVT,P,T,X**

**Input Values:**

**P** - Pressure  $p$  in bar  
**T** - Temperature  $t$  in °C  
**X** - Vapor fraction  $x$  (kg of saturated steam)/(kg wet steam)

**Result**

**DPDVTPTXMD4M, DPDVT or dpdvt\_ptx\_MD4M** - Derivative of pressure with respect to temperature (at constant specific volume) dpdvt in kPa/K

**Range of validity**

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $399.85^\circ\text{C}$   
 Pressure range: from  $p = 0.00001$  bar to 300 bar

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

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

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

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

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for  $t$  and  $p = -1000$ , or the given value for  $p$  and  $t = -1000$ , plus the value for  $x$  ( $x = 0$  or  $x = 1$ ). If  $p$  and  $t$  and  $x$  are entered as given values, the program will consider  $p$  and  $t$  to be appropriate to represent the vapor pressure curve.

Saturated liquid and Temperature ranges from  $t = 26.85^\circ\text{C}$  to  $t_c = 379.05^\circ\text{C}$   
 saturated vapor line: Pressure ranges from  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  bar

**Results for wrong input values**

Result **DPDVTPTXMD4M = -1000, DPDVT = -1000 or dpdvt\_ptx\_MD4M = -1000** for input values:

Single phase region:  $p > 300$  bar or  $p < 0.00001$  bar or  
 ( $x = -1$ )  $t > 399.85^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

Saturation lines: at  $p = -1000$  and  $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$   
 at  $t = -1000$  and  $p > p_c = 8.7747391$  bar  
 or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar or  
 at  $p > p_c = 8.7747391$  bar or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar and  
 $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

**References:** [1]

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

Function Name: **h\_ptx\_MD4M**

Subroutine with function value: **REAL\*8 FUNCTION HPTXMD4M(P,T,X)**  
for call from Fortran **REAL\*8 P,T,X**

Subroutine with parameter: **INTEGER\*4 FUNCTION C\_HPTXMD4M(H,P,T,X)**  
for call from DLL **REAL\*8 H,P,T,X**

### Input Values:

**P** - Pressure  $p$  in bar  
**T** - Temperature  $t$  in °C  
**X** - Vapor fraction  $x$  (kg of saturated steam)/(kg wet steam)

### Result

**HPTXMD4M, H** or **h\_ptx\_MD4M** - specific enthalpy  $h$  in kJ/kg

### Range of validity

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $399.85^\circ\text{C}$   
 Pressure range: from  $p = 0.00001$  bar to 300 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  $t$  and  $p = -1000$  or the given value for  $p$  and  $t = -1000$  and in both cases the value for  $x$  between 0 and 1 must be entered.

If  $p$  and  $t$  are entered as given values, the program considers  $p$  and  $t$  to be appropriate to represent the vapor pressure curve.

Wet steam region: Temperature ranges from  $t = 26.85^\circ\text{C}$  to  $t_c = 379.05^\circ\text{C}$   
 Pressure ranges from  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  bar

### Results for wrong input values

Result **HPTXMD4M = -1000, H = -1000** or **h\_ptx\_MD4M = -1000** for input values:

Single phase region:  $p > 300$  bar or  $p < 0.00001$  bar or  
 ( $x = -1$ )  $t > 399.85^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

Wet steam region: at  $p = -1000$  and  $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$   
 at  $t = -1000$  and  $p > p_c = 8.7747391$  bar  
 or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar or  
 at  $p > p_c = 8.7747391$  bar or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar and  
 $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

### References: [1]

## Isentropic Exponent $\kappa = f(p, t, x)$

Function Name: **kappa\_ptx\_MD4M**

Subroutine with function value: **REAL\*8 FUNCTION KAPPAPTXMD4M(P,T,X)**  
for call from Fortran **REAL\*8 P,T,X**

Subroutine with parameter: **INTEGER\*4 FUNCTION C\_KAPPAPTXMD4M(KAPPA, P,T,X)**  
for call from DLL **REAL\*8 KAPPA,P,T,X**

### Input Values:

**P** - Pressure  $p$  in bar  
**T** - Temperature  $t$  in °C  
**X** - Vapor fraction  $x$  (kg of saturated steam)/(kg wet steam)

### Result

**KAPPAPTXMD4M, KAPPA** or **kappa\_ptx\_MD4M** - Isentropic exponent  $\kappa = \frac{w^2}{p \cdot v}$

### Range of validity

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $399.85^\circ\text{C}$   
 Pressure range: from  $p = 0.00001$  bar to 300 bar

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

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

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

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

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for  $t$  and  $p = -1000$ , or the given value for  $p$  and  $t = -1000$ , plus the value for  $x$  ( $x = 0$  or  $x = 1$ ). If  $p$  and  $t$  and  $x$  are entered as given values, the program will consider  $p$  and  $t$  to be appropriate to represent the vapor pressure curve.

Saturated liquid and Temperature ranges from  $t = 26.85^\circ\text{C}$  to  $t_c = 379.05^\circ\text{C}$   
 saturated vapor line: Pressure ranges from  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  bar

### Results for wrong input values

Result **KAPPAPTXMD4M, KAPPA = -1000** or **kappa\_ptx\_MD4M = -1000** for input values:

Single phase region:  $p > 300$  bar or  $p < 0.00001$  bar or  
 ( $x = -1$ )  $t > 399.85^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

Saturation lines: at  $p = -1000$  and  $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$   
 at  $t = -1000$  and  $p > p_c = 8.7747391$  bar  
 or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar or  
 at  $p > p_c = 8.7747391$  bar or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar and  
 $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

### References: [1]

## Vapor Pressure $p_s = f(t)$

Function Name:	<b>ps_t_MD4M</b>
Subroutine with function value: for call from Fortran	<b>REAL*8 FUNCTION PSTMD4M(T)</b> <b>REAL*8 T</b>
Subroutine with parameter: for call from DLL	<b>INTEGER*4 FUNCTION C_PSTMD4M(PS,T)</b> <b>REAL*8 PS,T</b>

### Input Values:

T - Temperature  $t$  in °C

### Result

**PSTMD4M, PS** or **ps\_t\_MD4M** - Vapor pressure  $p_s$  in bar

### Range of validity

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $t_c = 379.05^\circ\text{C}$

### Results for wrong input values

Result **PSTMD4M = -1000, PS = -1000** or **ps\_t\_MD4M = -1000** for input values:

$t < 26.85^\circ\text{C}$  or  $t > t_c = 379.05^\circ\text{C}$

### References: [1]

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

Function Name: **rho\_ptx\_MD4M**

Subroutine with function value: **REAL\*8 FUNCTION RHOPTXMD4M(P,T,X)**  
 for call from Fortran **REAL\*8 P,T,X**

Subroutine with parameter: **INTEGER\*4 FUNCTION C\_RHOPTXMD4M(RHO,P,T,X)**  
 for call from DLL **REAL\*8 RHO,P,T,X**

**Input Values:**

**P** - Pressure  $p$  in bar  
**T** - Temperature  $t$  in °C  
**X** - Vapor fraction  $x$  (kg of saturated steam)/(kg wet steam)

**Result**

**RHO\_PTX\_MD4M, RHO or rho\_ptx\_MD4M** - Density  $\rho$  in kg/m<sup>3</sup>

**Range of validity**

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $399.85^\circ\text{C}$   
 Pressure range: from  $p = 0.00001$  bar to 300 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  $t$  and  $p = -1000$  or the given value for  $p$  and  $t = -1000$  and in both cases the value for  $x$  between 0 and 1 must be entered.

If  $p$  and  $t$  and  $x$  are entered as given values, the program considers  $p$  and  $t$  to be appropriate to represent the vapor pressure curve.

Wet steam region: Temperature ranges from  $t = 26.85^\circ\text{C}$  to  $t_c = 379.05^\circ\text{C}$   
 Pressure ranges from  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  bar

**Results for wrong input values**

Result **RHOPTXMD4M = -1000, RHO = -1000 or rho\_ptx\_MD4M = -1000** for input values:

Single phase region:  $p > 300$  bar or  $p < 0.00001$  bar or  
 ( $x = -1$ )  $t > 399.85^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

Wet steam region: at  $p = -1000$  and  $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$   
 at  $t = -1000$  and  $p > p_c = 8.7747391$  bar  
 or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar or  
 at  $p > p_c = 8.7747391$  bar or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar and  
 $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

**References: [1]**

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

Function Name: **s\_ptx\_MD4M**

Subroutine with function value: **REAL\*8 FUNCTION SPTXMD4M(P,T,X)**  
 for call from Fortran **REAL\*8 P,T,X**

Subroutine with parameter: **INTEGER\*4 FUNCTION C\_SPTXMD4M(S,P,T,X)**  
 for call from DLL **REAL\*8 S,P,T,X**

**Input Values:**

**P** - Pressure  $p$  in bar  
**T** - Temperature  $t$  in °C  
**X** - Vapor fraction  $x$  (kg of saturated steam)/(kg wet steam)

**Result**

**SPTXMD4M, S** or **s\_ptx\_MD4M** - Specific entropy  $s$  in kJ/kg K

**Range of validity**

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $399.85^\circ\text{C}$   
 Pressure range: from  $p = 0.00001$  bar to 300 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  $t$  and  $p = -1000$  or the given value for  $p$  and  $t = -1000$  and in both cases the value for  $x$  between 0 and 1 must be entered.

If  $p$  and  $t$  and  $x$  are entered as given values, the program considers  $p$  and  $t$  to be appropriate to represent the vapor pressure curve.

Wet steam region: Temperature ranges from  $t = 26.85^\circ\text{C}$  to  $t_c = 379.05^\circ\text{C}$   
 Pressure ranges from  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  bar

**Results for wrong input values**

Result **SPTXMD4M = -1000, S = -1000** or **s\_ptx\_MD4M = -1000** for input values:

Single phase region:  $p > 300$  bar or  $p < 0.00001$  bar or  
 ( $x = -1$ )  $t > 399.85^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

Wet steam region: at  $p = -1000$  and  $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$   
 at  $t = -1000$  and  $p > p_c = 8.7747391$  bar  
 or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar or  
 at  $p > p_c = 8.7747391$  bar or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar and  
 $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

**References: [1]**

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

Function Name: **t\_ph\_MD4M**

Subroutine with function value: **REAL\*8 FUNCTION TPHMD4M(P,H)**  
 for call from Fortran **REAL\*8 P,H**

Subroutine with parameter: **INTEGER\*4 FUNCTION C\_TPHMD4M(T,P,H)**  
 for call from DLL **REAL\*8 T,P,H**

**Input Values:**

**P** - Pressure  $p$  in bar  
**H** - Specific enthalpy  $h$  in kJ/kg

**Result**

**TPHMD4M, T or t\_ph\_MD4M** - Temperature  $t$  in °C

**Range of validity**

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $399.85^\circ\text{C}$   
 Pressure range: from  $p = 0.00001$  bar to  $300$  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  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  bar

**Results for wrong input values**

Result **T\_PH\_MD4M, T = -1000** or **t\_ph\_MD4M = -1000** for input values:

Single phase region: at  $p > 300$  bar or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar or  
 ( $x = -1$ ) at result  $t > 399.85^\circ\text{C}$ ,  $t < 26.85^\circ\text{C}$

Boiling or dew curve: at  $p > p_c = 8.7747391$  bar or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar  
 at result  $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

**References: [1]**

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

Function Name: **t\_ps\_MD4M**

Subroutine with function value: **REAL\*8 FUNCTION TPSMD4M(P,S)**  
 for call from Fortran **REAL\*8 P,S**

Subroutine with parameter: **INTEGER\*4 FUNCTION C\_TPSMD4M(T,P,S)**  
 for call from DLL **REAL\*8 T,P,S**

### Input Values:

**P** - Pressure  $p$  in bar  
**S** - Specific entropy  $s$  in kJ/(kg K)

### Result

**TPSMD4M, T or t\_ps\_MD4M** - Temperature  $t$  in °C

### Range of validity

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $399.85^\circ\text{C}$   
 Pressure range: from  $p = 0.00001$  bar to  $300$  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. Afterwards the calculation of  $t$  in the appropriate region will be carried out.

Wet steam region: Pressure ranges from  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  bar

### Results for wrong input values

Result **T\_PS\_MD4M, T = -1000** or **t\_ps\_MD4M = -1000** for input values:

Single phase region: at  $p > 300$  bar or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar or  
 ( $x = -1$ ) at result  $t > 399.85^\circ\text{C}$ ,  $t < 26.85^\circ\text{C}$

Boiling or dew curve: at  $p > p_c = 8.7747391$  bar or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar  
 at result  $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

### References: [1]

## Saturation Temperature $t_s = f(p)$

Function Name:	<b>ts_p_MD4M</b>
Subroutine with function value: for call from Fortran	<b>REAL*8 FUNCTION TSPMD4M(P)</b> <b>REAL*8 P</b>
Subroutine with parameter: for call from DLL	<b>INTEGER*4 FUNCTION C_TSPMD4M(TS,P)</b> <b>REAL*8 TS,P</b>

### Input Values:

**P** - Pressure  $p$  in bar

### Result

**TSPMD4M, TS** or **ts\_p\_MD4M** - Saturation temperature  $t_s$  in °C

### Range of validity

Pressure range : from  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  bar

### Results for wrong input values

Result **TSPMD4M = -1000**, **TS = -1000** or **ts\_p\_MD4M = -1000** for input values:

$p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar or  $p > p_c = 8.7747391$  bar

### References: [1]

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

Function Name: **u\_ptx\_MD4M**

Subroutine with function value: **REAL\*8 FUNCTION UPTXMD4M(P,T,X)**  
 for call from Fortran **REAL\*8 P,T,X**

Subroutine with parameter: **INTEGER\*4 FUNCTION C\_UPTXMD4M(U,P,T,X)**  
 for call from DLL **REAL\*8 U,P,T,X**

### Input Values:

**P** - Pressure  $p$  in bar  
**T** - Temperature  $t$  in °C  
**X** - Vapor fraction  $x$  (kg of saturated steam)/(kg wet steam)

### Result

**UPTXMD4M, U** or **u\_ptx\_MD4M** - Specific internal energy  $u$  in kJ/kg

### Range of validity

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $399.85^\circ\text{C}$   
 Pressure range: from  $p = 0.00001$  bar to 300 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  $t$  and  $p = -1000$  or the given value for  $p$  and  $t = -1000$  and in both cases the value for  $x$  between 0 and 1 must be entered.

If  $p$  and  $t$  and  $x$  are entered as given values, the program considers  $p$  and  $t$  to be appropriate to represent the vapor pressure curve.

Wet steam region: Temperature ranges from  $t = 26.85^\circ\text{C}$  to  $t_c = 379.05^\circ\text{C}$   
 Pressure ranges from  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  bar

### Results for wrong input values

Result **UPTXMD4M = -1000, U = -1000** or **u\_ptx\_MD4M = -1000** for input values:

Single phase region:  $p > 300$  bar or  $p < 0.00001$  bar or  
 ( $x = -1$ )  $t > 399.85^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

Wet steam region: at  $p = -1000$  and  $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$   
 at  $t = -1000$  and  $p > p_c = 8.7747391$  bar  
 or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar or  
 at  $p > p_c = 8.7747391$  bar or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar and  
 $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

### References: [1]

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

Function Name: **v\_ptx\_MD4M**

Subroutine with function value: **REAL\*8 FUNCTION VPTXMD4M(P,T,X)**  
 for call from Fortran **REAL\*8 P,T,X**

Subroutine with parameter: **INTEGER\*4 FUNCTION C\_VPTXMD4M(V,P,T,X)**  
 for call from DLL **REAL\*8 V,P,T,X**

**Input Values:**

**P** - Pressure  $p$  in bar  
**T** - Temperature  $t$  in °C  
**X** - Vapor fraction  $x$  (kg of saturated steam)/(kg wet steam)

**Result**

**VPTXMD4M, V or v\_ptx\_MD4M** - Specific volume  $v$  in m<sup>3</sup>/kg

**Range of validity**

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $399.85^\circ\text{C}$   
 Pressure range: from  $p = 0.00001$  bar to 300 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  $t$  and  $p = -1000$  or the given value for  $p$  and  $t = -1000$  and in both cases the value for  $x$  between 0 and 1 must be entered.

If  $p$  and  $t$  and  $x$  are entered as given values, the program considers  $p$  and  $t$  to be appropriate to represent the vapor pressure curve.

Wet steam region: Temperature ranges from  $t = 26.85^\circ\text{C}$  to  $t_c = 379.05^\circ\text{C}$   
 Pressure ranges from  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  bar

**Results for wrong input values**

Result **VPTXMD4M = -1000, V = -1000 or v\_ptx\_MD4M = -1000** for input values:

Single phase region:  $p > 300$  bar or  $p < 0.00001$  bar or  
 ( $x = -1$ )  $t > 399.85^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

Wet steam region: at  $p = -1000$  and  $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$   
 at  $t = -1000$  and  $p > p_c = 8.7747391$  bar  
 or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar or  
 at  $p > p_c = 8.7747391$  bar or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar and  
 $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

**References: [1]**

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

Function Name: **w\_ptx\_MD4M**

Subroutine with function value: **REAL\*8 FUNCTION WPTXMD4M(P,T,X)**  
 for call from Fortran **REAL\*8 P,T,X**

Subroutine with parameter: **INTEGER\*4 FUNCTION C\_WPTXMD4M(W,P,T,X)**  
 for call from DLL **REAL\*8 W,P,T,X**

**Input Values:**

**P** - Pressure  $p$  in bar  
**T** - Temperature  $t$  in °C  
**X** - Vapor fraction  $x$  (kg of saturated steam)/(kg wet steam)

**Result**

**WPTXMD4M, W** or **w\_ptx\_MD4M** - Speed of sound  $w$  in m/s

**Range of validity**

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $399.85^\circ\text{C}$   
 Pressure range: from  $p = 0.00001$  bar to 300 bar

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

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

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

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

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for  $t$  and  $p = -1000$ , or the given value for  $p$  and  $t = -1000$ , plus the value for  $x$  ( $x = 0$  or  $x = 1$ ). If  $p$  and  $t$  and  $x$  are entered as given values, the program will consider  $p$  and  $t$  to be appropriate to represent the vapor pressure curve.

Saturated liquid and Temperature ranges from  $t = 26.85^\circ\text{C}$  to  $t_c = 379.05^\circ\text{C}$   
 saturated vapor line: Pressure ranges from  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  bar

**Results for wrong input values**

Result **WPTXMD4M = -1000, W = -1000** or **w\_ptx\_MD4M = -1000** for input values:

Single phase region:  $p > 300$  bar or  $p < 0.00001$  bar or  
 ( $x = -1$ )  $t > 399.85^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

Boiling or dew curve: at  $p = -1000$  and  $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$   
 at  $t = -1000$  and  $p > p_c = 8.7747391$  bar  
 or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar or  
 at  $p > p_c = 8.7747391$  bar or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar and  
 $t > t_c = 379.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

**References: [1]**

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

Function Name: **x\_ph\_MD4M**

Subroutine with function value: **REAL\*8 FUNCTION XPHMD4M(P,H)**  
 for call from Fortran **REAL\*8 P,H**

Subroutine with parameter: **INTEGER\*4 FUNCTION C\_XPHMD4M(X,P,H)**  
 for call from DLL **REAL\*8 X,P,H**

### Input Values:

**P** - Pressure  $p$  in bar  
**H** - Specific enthalpy  $h$  in kJ/kg

### Result

**XPHMD4M, X or x\_ph\_MD4M** - Vapor fraction  $x$  in (kg saturated steam/kg wet steam)

### Range of validity

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $t_c = 380.05^\circ\text{C}$   
 Pressure range: from  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  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  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  bar

### Results for wrong input values

Result **X\_PH\_MD4M, X = -1** or **x\_ph\_MD4M = -1** for input values:

If the state point is located in the single phase region:  
 $p > p_c = 8.7747391$  bar or  $p < 0.00001093377$  bar

### References: [1]

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

Function Name: **x\_ps\_MD4M**

Subroutine with function value: **REAL\*8 FUNCTION XPSMD4M(P,S)**  
 for call from Fortran **REAL\*8 P,S**

Subroutine with parameter: **INTEGER\*4 FUNCTION C\_XPSMD4M(X,P,S)**  
 for call from DLL **REAL\*8 X,P,S**

### Input Values:

**P** - Pressure  $p$  in bar  
**S** - Specific entropy  $s$  in kJ/(kg K)

### Result

**XPSMD4M, X or x\_ps\_MD4M** - Vapor fraction  $x$  in (kg saturated steam/kg wet steam)

### Range of validity

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $t_c = 380.05^\circ\text{C}$   
 Pressure range: from  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  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  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  bar

### Results for wrong input values

Result **X\_PS\_MD4M, X = -1** or **x\_ps\_MD4M = -1** for input values:

If the state point is located in the single phase region:  
 $p > p_c = 8.7747391$  bar or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar

### References: [1]

## Compression Factor $Z = f(p, t, x)$

Function Name: **Z\_ptx\_MD4M**

Subroutine with function value: **REAL\*8 FUNCTION ZPTXMD4M(P,T,X)**  
 for call from Fortran **REAL\*8 P,T,X**

Subroutine with parameter: **INTEGER\*4 FUNCTION C\_ZPTXMD4M(Z,P,T,X)**  
 for call from DLL **REAL\*8 Z,P,T,X**

### Input Values:

**P** - Pressure  $p$  in bar  
**T** - Temperature  $t$  in °C  
**X** - Vapor fraction  $x$  (kg of saturated steam)/(kg wet steam)

### Result

**ZPTXMD4M, Z or Z\_ptx\_MD4M** - Compression Factor

### Range of validity

Temperature range: from  $t = 26.85^\circ\text{C}$  to  $399.85^\circ\text{C}$   
 Pressure range: from  $p = 0.00001$  bar to 300 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 on the boiling curve,  $x = 0$  must be entered. When calculating saturated steam (dew curve)  $x = 1$  is entered as given value. The calculation for  $x$  values between 0 and 1 is not possible.

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.

Boiling and dew curve: Temperature ranges from  $t = 26.85^\circ\text{C}$  to  $t_c = 380.05^\circ\text{C}$   
 Pressure ranges from  $p_s(26.85^\circ\text{C}) = 0.00001093377$  bar to  $p_c = 8.7747391$  bar

### Results for wrong input values

Result **ZPTXMD4M = -1000, Z = -1000 or Z\_ptx\_MD4M = -1000** for input values:

Single phase region:  $p > 300$  bar or  $p < 0.00001$  bar or  
 ( $x = -1$ )  $t > 399.85^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

Boiling or dew curve: at  $p = -1000$  and  $t > t_c = 380.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$   
 at  $t = -1000$  and  $p > p_c = 8.7747391$  bar  
 or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar or  
 at  $p > p_c = 8.7747391$  bar or  $p < p_s(26.85^\circ\text{C}) = 0.00001093377$  bar and  
 $t > t_c = 380.05^\circ\text{C}$  or  $t < 26.85^\circ\text{C}$

### References: [1]

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

### Water and Steam

#### Library LibIF97

- Industrial Formulation IAPWS-IF97 (Revision 2007)
- Supplementary Standards
  - IAPWS-IF97-S01
  - 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:  
 $\text{CO}_2$  - Span, Wagner     $\text{H}_2\text{O}$  - IAPWS-95  
 $\text{O}_2$  - Schmidt, Wagner     $\text{N}_2$  - Span et al.  
 Ar - Tegeler et al.  
 and of the ideal gases:  
 $\text{SO}_2$ ,  $\text{CO}$ , Ne  
 (Scientific Formulation of Bucker 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	$\text{H}_2\text{O}$	$\text{F}_2$	Propane
$\text{N}_2$	$\text{SO}_2$	$\text{NH}_3$	Iso-Butane
$\text{O}_2$	$\text{H}_2$	Methane	n-Butane
CO	$\text{H}_2\text{S}$	Ethane	Benzene
$\text{CO}_2$	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](http://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 Bucker and Wagner (2006)

#### n-Butane

#### Library LibButane\_n

Formulation of Bucker 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

$\text{C}_2\text{H}_6\text{O}_2$	Ethylene glycol
$\text{C}_3\text{H}_8\text{O}_2$	Propylene glycol
$\text{C}_2\text{H}_5\text{OH}$	Ethanol
$\text{CH}_3\text{OH}$	Methanol
$\text{C}_3\text{H}_8\text{O}_3$	Glycerol
$\text{K}_2\text{CO}_3$	Potassium carbonate
$\text{CaCl}_2$	Calcium chloride
$\text{MgCl}_2$	Magnesium chloride
$\text{NaCl}$	Sodium chloride
$\text{C}_2\text{H}_3\text{KO}_2$	Potassium acetate
$\text{CHKO}_2$	Potassium formate
$\text{LiCl}$	Lithium chloride
$\text{NH}_3$	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  $C_{14}H_{42}O_6Si_6$  **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<sub>2</sub>S** **Library LibH2S**

Nitrous oxide **N<sub>2</sub>O** **Library LibN2O**

Sulfur dioxide **SO<sub>2</sub>** **Library LibSO2**

Acetone  $C_3H_6O$  **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

**For more information please contact:**

KCE-ThermoFluidProperties UG (limited liability) & Co. KG  
Professor Hans-Joachim Kretschmar

Wallotstr. 3  
01307 Dresden, Germany

Internet: [www.thermofluidprop.com](http://www.thermofluidprop.com)

E-mail: [info@thermofluidprop.com](mailto:info@thermofluidprop.com)

Phone: +49-351-27597860

Mobile: +49-172-7914607

Fax: +49-3222-4262250

**The following thermodynamic and transport properties can be calculated<sup>a</sup>:****Thermodynamic Properties**

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

**Transport Properties**

- Dynamic viscosity  $\eta$
- Kinematic viscosity  $\nu$
- Thermal conductivity  $\lambda$
- Prandtl number  $Pr$

**Backward Functions**

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

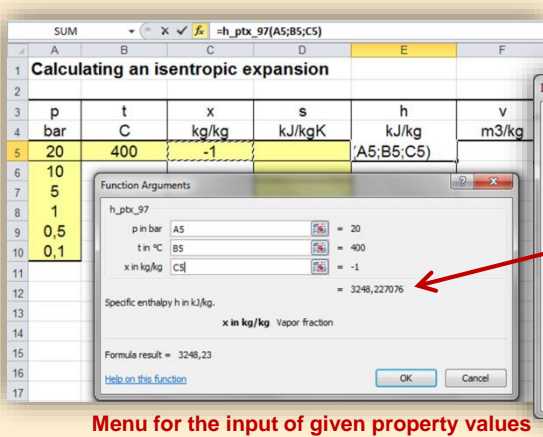
**Thermodynamic Derivatives**

- Partial derivatives can be calculated.

<sup>a</sup> Not all of these property functions are available in all property libraries.

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

## Add-In FluidEXL<sup>Graphics</sup> for Excel<sup>®</sup>



**Calculating an isentropic expansion**

p	t	x	s	h	v
bar	°C	kg/kg	kJ/kgK	kJ/kg	m³/kg
20	400	-1		3248.22706	

**Function Arguments**

h\_ptx\_97

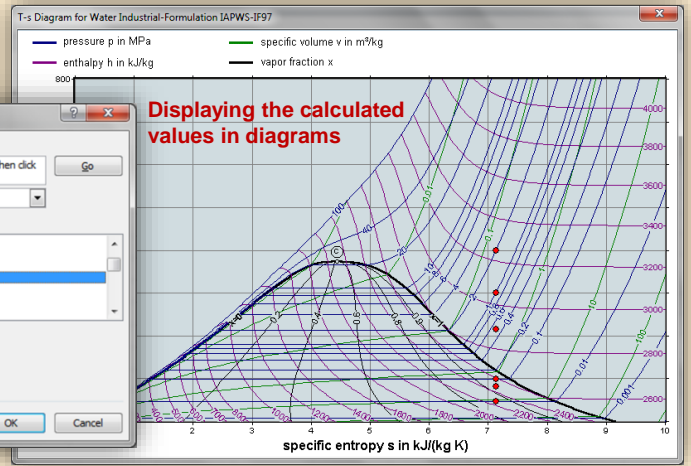
p in bar: 20  
t in °C: 400  
x in kg/kg: -1

Specific enthalpy h in kJ/kg: 3248.22706

**Menu for the input of given property values**

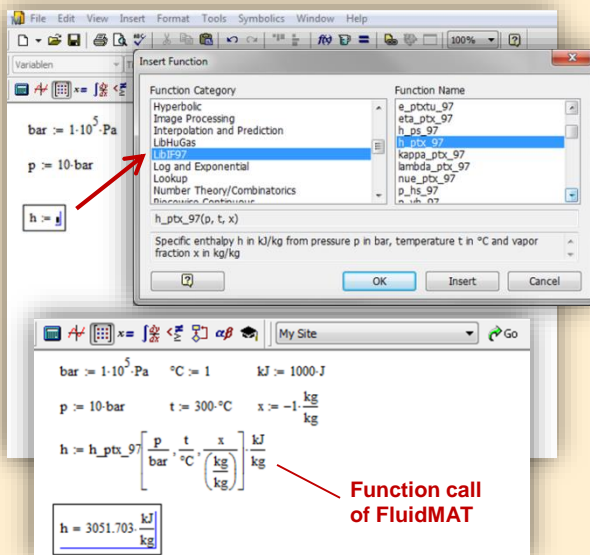
**Choosing a property library and a function**

**Displaying the calculated values in diagrams**



## Add-In FluidMAT for Mathcad<sup>®</sup>

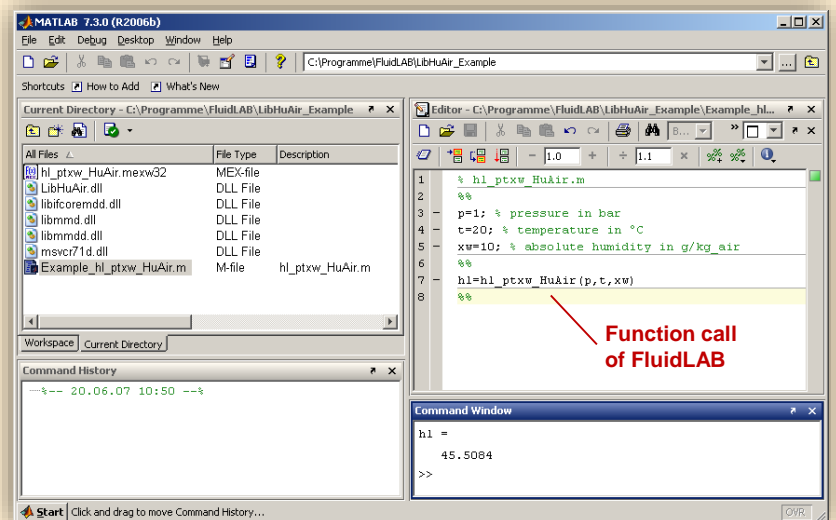
The property libraries can be used in Mathcad<sup>®</sup>.



**Function call of FluidMAT**

## Add-In FluidLAB for MATLAB<sup>®</sup>

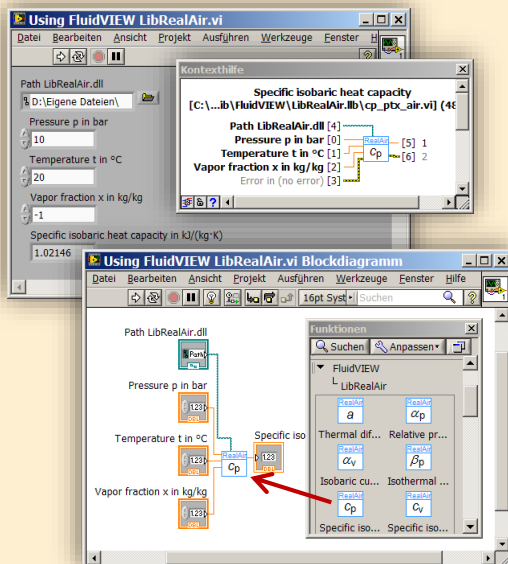
Using the Add-In FluidLAB the property functions can be called in MATLAB<sup>®</sup>.



**Function call of FluidLAB**

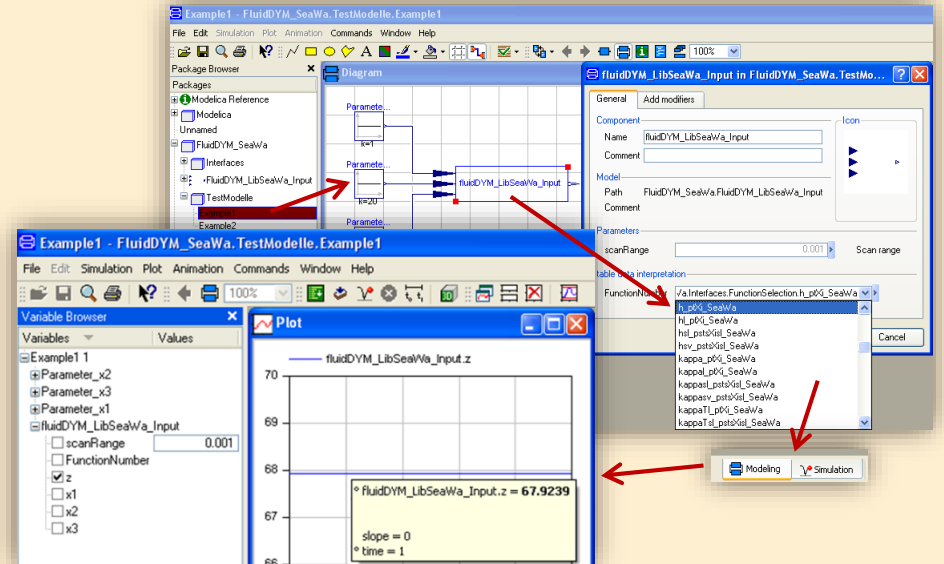
## Add-On FluidVIEW for LabVIEW<sup>™</sup>

The property functions can be calculated in LabVIEW<sup>™</sup>.

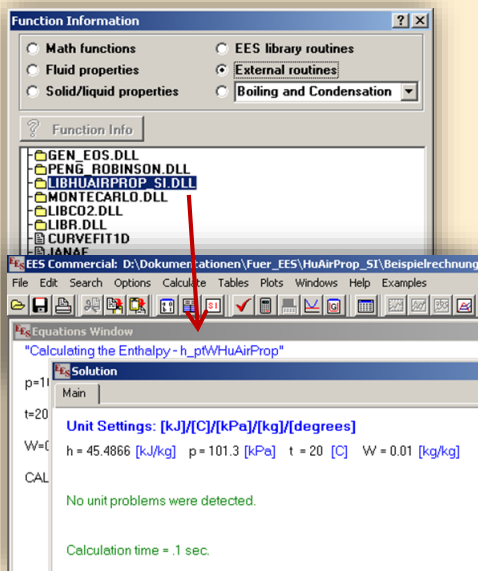


## Add-In FluidDYM for DYMOLA<sup>®</sup> (Modelica) and SimulationX<sup>®</sup>

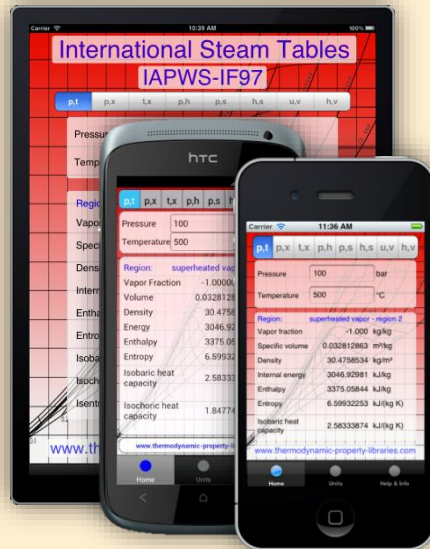
The property functions can be called in DYMOLA<sup>®</sup> and SimulationX<sup>®</sup>.



## 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](http://www.thermofluidprop.com)

**Zittau's Fluid Property Calculator**

Fluid:

Function:

Unit System:

Enter given values: [Range of validity](#)

Pressure p:  bar

Temperature t:  °C

Vapor fraction x:  kg/kg

**Calculate / Recalculate**

**Result:**

Specific enthalpy h = 3097.38 kJ/kg

For further information on property libraries available for EXCEL®, MATLAB®, Mathcad®, Engineering Equation Solver®, DYMOLA® (Modelica), SimulationX®, and LabView® click [here](#)

An App for calculating steam properties on iPhone, iPad, and iPod touch can be found [here](#)

PDF with the description

© Zittau/Görlitz University of Applied Sciences  
Faculty of Mechanical Engineering  
Department of Technical Thermodynamics  
Prof. Hans-Joachim Kretzschmar  
Dr. Ines Stöcker  
Programmer: Joachim Posselt

Tel.: +49-3583-61-1946 or -1981  
Fax: +49-3583-61-1946  
E-mail: [info@thermofluidprop.com](mailto:info@thermofluidprop.com)  
[www.thermofluidprop.com](http://www.thermofluidprop.com)  
[www.thermofluidprop.com](http://www.thermofluidprop.com)  
[www.thermofluidprop.com](http://www.thermofluidprop.com)  
[www.thermofluidprop.com](http://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 83    TI 84    TI 89



TI Voyage 200



TI 92

## For more information please contact:

KCE-ThermoFluidProperties UG (limited liability) & Co. KG  
Professor Hans-Joachim Kretzschmar

Wallotstr. 3  
01307 Dresden, Germany

Internet: [www.thermofluidprop.com](http://www.thermofluidprop.com)  
E-mail: [info@thermofluidprop.com](mailto:info@thermofluidprop.com)  
Phone: +49-351-27597860  
Mobile: +49-172-7914607  
Fax: +49-3222-4262250

The following thermodynamic and transport properties<sup>a</sup> 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  $\rho$
- Specific volume  $v$
- Enthalpy  $h$
- Internal energy  $u$
- Entropy  $s$
- Exergy  $e$
- Isobaric heat capacity  $c_p$
- Isochoric heat capacity  $c_v$
- Isentropic exponent  $\kappa$
- Speed of sound  $w$
- Surface tension  $\sigma$

### Transport Properties

- Dynamic viscosity  $\eta$
- Kinematic viscosity  $\nu$
- Thermal conductivity  $\lambda$
- 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.

<sup>a</sup> Not all of these property functions are available in all property libraries.

## 5. References

- [1] Colonna, P.; Nannan, N. R.; Guardone, A.; Lemmon, E. W.  
Multiparameter equations of state for selected siloxanes  
Fluid Phase Equilibria, 244, (2006) S. 193-211

## 6. Satisfied Customers

Date: 05/2018

The following companies and institutions use the property libraries

- FluidEXL *Graphics* for Excel®
- FluidLAB for MATLAB®
- FluidMAT for Mathcad®
- FluidEES for Engineering Equation Solver® EES
- FluidDYM for Dymola® (Modelica) and SimulationX®
- FluidVIEW for LabVIEW™.

### 2018

Universität Madrid, Madrid, Spanien	05/2018
HS Zittau/ Görlitz, Fakultät Wirtschaft, Zittau	05/2018
HS Niederrhein, Krefeld	05/2018
GRS, Köln	03/2018
RONAL AG, Härklingen, Schweiz	02/2018
Ingenieurbüro Leipert, Riegelsberg	02/2018
AIXPROCESS, Aachen	02/2018
KRONES, Neutraubling	02/2018
Doosan Lentjes, Ratingen	01/2018

### 2017

Compact Kältetechnik, Dresden	12/2017
Endress + Hauser Messtechnik GmbH +Co. KG, Hannover	12/2017
TH Mittelhessen, Gießen	11/2017
Haarslev Industries, Sønderød, Denmark	11/2017
Hochschule Zittau/Görlitz, Fachgebiet Energiesystemtechnik	11/2017
ATESTEO, Alsdorf	10/2017
Wijbenga, PC Geldermalsen, Netherlands	10/2017
Fels-Werke GmbH, Elbingerode	10/2017
KIT Karlsruhe, Institute für Neutronenphysik und Reaktortechnik	09/2017
Air-Consult, Jena	09/2017
Papierfabrik Koehler, Oberkirch	09/2017
ZWILAG, Würenlingen, Switzerland	09/2017
TLK-Thermo Universität Braunschweig, Braunschweig	08/2017
Fichtner IT Consulting AG, Stuttgart	07/2017
Hochschule Ansbach, Ansbach	06/2017
RONAL, Härkingen, Switzerland	06/2017
BORSIG Service, Berlin	06/2017

BOGE Kompressoren, Bielefeld	06/2017
STEAG Energy Services, Zwingenberg	06/2017
CES clean energy solutions, Wien, Austria	04/2017
Princeton University, Princeton, USA	04/2017
B2P Bio-to-Power, Wadersloh	04/2017
TU Dresden, Institute for Energy Engineering, Dresden	04/2017
SAINT-GOBAIN, Vaujours, France	03/2017
TU Bergakademie Freiberg, Chair of Thermodynamics, Freiberg	03/2017
SCHMIDT + PARTNER, Therwil, Switzerland	03/2017
KAESER Kompressoren, Gera	03/2017
F&R, Praha, Czech Republic	03/2017
ULT Umwelt-Lufttechnik, Löbau	02/2017
JS Energie & Beratung, Erding	02/2017
Kelvion Braze PHE, Nobitz-Wilchwitz	02/2017
MTU Aero Engines, München	02/2017
Hochschule Zittau/Görlitz, IPM	01/2017
CombTec ProCE, Zittau	01/2017
SHELL Deutschland Oil, Wesseling	01/2017
MARTEC Education Center, Frederikshaven, Denmark	01/2017
SynErgy Thermal Management, Krefeld	01/2017

## 2016

BOGE Druckluftsysteme, Bielefeld	12/2016
BFT Planung, Aachen	11/2016
Midiplan, Bietigheim-Bissingen	11/2016
BBE Barnich IB	11/2016
Wenisch IB,	11/2016
INL, Idaho Falls	11/2016
TU Kältetechnik, Dresden	11/2016
Kopf SynGas, Sulz	11/2016
INTVEN, Bellevue (USA)	11/2016
DREWAG Dresden, Dresden	10/2016
AGO AG Energie+Anlagen, Kulmbach	10/2016
Universität Stuttgart, ITW, Stuttgart	09/2016
Pöry Deutschland GmbH, Dresden	09/2016
Siemens AG, Erlangen	09/2016
BASF über Fichtner IT Consulting AG	09/2016
B+B Engineering GmbH, Magdeburg	09/2016
Wilhelm Büchner Hochschule, Pfungstadt	08/2016

Webasto Thermo & Comfort SE, Gliching	08/2016
TU Dresden, Dresden	08/2016
Endress+Hauser Messtechnik GmbH+Co. KG, Hannover	08/2016
D + B Kältetechnik, Althausen	07/2016
Fichtner IT Consulting AG, Stuttgart	07/2016
AB Electrolux, Krakow, Poland	07/2016
ENEXIO Germany GmbH, Herne	07/2016
VPC GmbH, Vetschau/Spreewald	07/2016
INWAT, Lodz, Poland	07/2016
E.ON SE, Düsseldorf	07/2016
Planungsbüro Waidhas GmbH, Chemnitz	07/2016
EEB Enerko, Aldershoven	07/2016
IHEBA Naturenergie GmbH & Co. KG, Pfaffenhofen	07/2016
SSP Kälteplaner AG, Wolfertschwenden	07/2016
EEB ENERKO Energiewirtschaftliche Beratung GmbH, Berlin	07/2016
BOGE Kompressoren Otto BOGE GmbH & Co KG, Bielefeld	06/2016
Universidad Carlos III de Madrid, Madrid, Spain	04/2016
INWAT, Lodzi, Poland	04/2016
Planungsbüro Waidhas GmbH, Chemnitz	04/2016
STEAG Energy Services GmbH, Laszlo Küppers, Zwingenberg	03/2016
WULFF & UMAG Energy Solutions GmbH, Husum	03/2016
FH Bielefeld, Bielefeld	03/2016
EWT Eckert Wassertechnik GmbH, Celle	03/2016
ILK Institut für Luft- und Kältetechnik GmbH, Dresden	02/2016, 06/2016 (2x)
IEV KEMA - DNV GV – Energie, Dresden	02/2016
Allborg University, Department of Energie, Aalborg, Denmark	02/2016
G.A.M. Heat GmbH, Gräfenhainichen	02/2016
Institut für Luft- und Kältetechnik, Dresden	02/2016, 05/2016, 06/2016
Bosch, Stuttgart	02/2016
INL Idaho National Laboratory, Idaho, USA	11/2016, 01/2016
Friedl ID, Wien, Austria	01/2016
Technical University of Dresden, Dresden	01/2016

## 2015

EES Enerko, Aachen	12/2015
Ruldolf IB, Strau, Austria	12/2015
Allborg University, Department of Energie, Aalborg, Denmark	12/2015
University of Lyubljana, Slovenia	12/2015
Steinbrecht IB, Berlin	11/2015
Universidad Carlos III de Madrid, Madrid, Spain	11/2015
STEAK, Essen	11/2015

Bosch, Lohmar	10/2015
Team Turbo Machines, Rouen, France	09/2015
BTC – Business Technology Consulting AG, Oldenburg	07/2015
KIT Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen	07/2015
ILK, Dresden	07/2015
Schniewindt GmbH & Co. KG, Neuenwalde	08/2015

## 2014

PROJEKTPLAN, Dohna	04/2014
Technical University of Vienna, Austria	04/2014
MTU Aero Engines AG, Munich	04/2014
GKS, Schweinfurt	03/2014
Technical University of Nuremberg	03/2014
EP-E, Niederstetten	03/2014
Rückert NatUrgas GmbH, Lauf	03/2014
YESS-World, South Korea	03/2014
ZAB, Dessau	02/2014
KIT-TVT, Karlsruhe	02/2014
Stadtwerke Neuburg	02/2014
COMPAREX, Leipzig for RWE Essen	02/2014
Technical University of Prague, Czech Republic	02/2014
HS Augsburg	02/2014
Envi-con, Nuremberg	01/2014
DLR, Stuttgart	01/2014
Doosan Lentjes, Ratingen	01/2014
Technical University of Berlin	01/2014
Technical University of Munich	01/2014
Technical University of Braunschweig	01/2014
M&M Turbinentechnik, Bielefeld	01/2014

## 2013

TRANTER-GmbH, Artern	12/2013
SATAKE, Shanghai, China	12/2013
VOITH, Kunshan, China	12/2013
ULT, Löbau	12/2013
MAN, Copenhagen, Dänemark	11/2013
DREWAG, Dresden	11/2013
Haarslev Industries, Herlev, Dänemark	11/2013
STEAG, Herne	11/2013, 12/2013
Ingersoll-Rand, Oberhausen	11/2013
Wilhelm-Büchner HS, Darmstadt	10/2013

IAV, Chemnitz	10/2013
Technical University of Regensburg	10/2013
PD-Energy, Bitterfeld	09/2013
Thermofin, Heinsdorfergrund	09/2013
SHI, New Jersey, USA	09/2013
M&M Turbinentechnik, Bielefeld	08/2013
BEG-BHV, Bremerhaven	08/2013
TIG-Group, Husum	08/2013
COMPAREX, Leipzig	08/2013, 11/2013
for RWE Essen	12/2013
University of Budapest, Hungary	08/2013
Siemens, Frankenthal	08/2013, 10/2013
	11/2013
VGB, Essen	07/2013, 11/2013
Brunner Energieberatung, Zurich, Switzerland	07/2013
Technical University of Deggendorf	07/2013
University of Maryland, USA	07/2013, 08/2013
University of Princeton, USA	07/2013
NIST, Boulder, USA	06/2013
IGUS GmbH, Dresden	06/2013
BHR Bilfinger, Essen	06/2013
SÜDSALZ, Bad Friedrichshall	06/2013, 12/2013
Technician School of Berlin	05/2013
KIER, Gajeong-ro, Südkorea	05/2013
Schwing/Stetter GmbH, Memmingen	05/2013
Vattenfall, Berlin	05/2013
AUTARK, Kleinmachnow	05/2013
STEAG, Zwingenberg	05/2013
Hochtief, Düsseldorf	05/2013
University of Stuttgart	04/2013
Technical University -Bundeswehr, Munich	04/2013
Rerum Cognitio Forschungszentrum, Frankfurt	04/2013
Kältetechnik Dresden + Bremen, Alfhausen	04/2013
University Auckland, New Zealand	04/2013
MASDAR Institut, Abu Dhabi, United Arab Emirates	03/2013
Simpelkamp, Dresden	02/2013
VEO, Eisenhüttenstadt	02/2013
ENTEC, Auerbach	02/2013
Caterpillar, Kiel	02/2013
Technical University of Wismar	02/2013
Technical University of Dusseldorf	02/2013

ILK, Dresden	01/2013, 08/2013
Fichtner IT, Stuttgart	01/2013, 11/2013
Schnepf Ingeniuerbüro, Nagold	01/2013
Schütz Engineering, Wadgassen	01/2013
Endress & Hauser, Reinach, Switzerland	01/2013
Oschatz GmbH, Essen	01/2013
frischli Milchwerke, Rehburg-Loccum	01/2013

## 2012

Voith, Bayreuth	12/2012
Technical University of Munich	12/2012
Dillinger Huette	12/2012
University of Stuttgart	11/2012
Siemens, Muehlheim	11/2012
Sennheiser, Hannover	11/2012
Oschatz GmbH, Essen	10/2012
Fichtner IT, Stuttgart	10/2012, 11/2012
Helbling Technik AG, Zurich, Switzerland	10/2012
University of Duisburg	10/2012
Rerum Cognitio Forschungszentrum, Frankfurt	09/2012
Pöry Deutschland GmbH, Dresden	08/2012
Extracciones, Guatemala	08/2012
RWE, Essen	08/2012
Weghaus Consulting Engineers, Wuerzburg	08/2012
GKS, Schweinfurt	07/2012
COMPAREX, Leipzig for RWE Essen	07/2012
GEA, Nobitz	07/2012
Meyer Werft, Papenburg	07/2012
STEAG, Herne	07/2012
GRS, Cologne	06/2012
Fichtner IT Consult, Chennai, India	06/2012
Siemens, Freiburg	06/2012
Nikon Research of America, Belmont, USA	06/2012
Niederrhein University of Applied Sciences, Krefeld	06/2012
STEAG, Zwingenberg	06/2012
Mainova, Frankfurt on Main via Fichtner IT Consult	05/2012
Endress & Hauser	05/2012
PEU, Espenheim	05/2012
Luzern University of Applied Sciences, Switzerland	05/2012

BASF, Ludwigshafen (general license) via Fichtner IT Consult	05/2012
SPX Balcke-Dürr, Ratingen	05/2012, 07/2012
Gruber-Schmidt, Wien, Austria	04/2012
Vattenfall, Berlin	04/2012
ALSTOM, Baden	04/2012
SKW, Piesteritz	04/2012
TERA Ingegneria, Trento, Italy	04/2012
Siemens, Erlangen	04/2012, 05/2012
LAWI Power, Dresden	04/2012
Stadtwerke Leipzig	04/2012
SEITZ, Wetzikon, Switzerland	03/2012, 07/2012
M & M, Bielefeld	03/2012
Sennheiser, Wedemark	03/2012
SPG, Montreuil Cedex, France	02/2012
German Destillation, Sprendlingen	02/2012
Lopez, Munguia, Spain	02/2012
Endress & Hauser, Hannover	02/2012
Palo Alto Research Center, USA	02/2012
WIPAK, Walsrode	02/2012
Freudenberg, Weinheim	01/2012
Fichtner, Stuttgart	01/2012
airinotec, Bayreuth	01/2012, 07/2012
University Auckland, New Zealand	01/2012
VPC, Vetschau	01/2012
Franken Guss, Kitzingen	01/2012

## 2011

XRG-Simulation, Hamburg	12/2011
Smurfit Kappa PPT, AX Roermond, Netherlands	12/2011
AWTEC, Zurich, Switzerland	12/2011
eins-energie, Bad Elster	12/2011
BeNow, Rodenbach	11/2011
Luzern University of Applied Sciences, Switzerland	11/2011
GMVA, Oberhausen	11/2011
CCI, Karlsruhe	10/2011
W.-Büchner University of Applied Sciences, Pfungstadt	10/2011
PLANAIR, La Sagne, Switzerland	10/2011
LAWI, Dresden	10/2011
Lopez, Munguia, Spain	10/2011
University of KwaZulu-Natal, Westville, South Africa	10/2011

Voith, Heidenheim	09/2011
SpgBe Montreal, Canada	09/2011
SPG TECH, Montreuil Cedex, France	09/2011
Voith, Heidenheim-Mergelstetten	09/2011
MTU Aero Engines, Munich	08/2011
MIBRAG, Zeitz	08/2011
RWE, Essen	07/2011
Fels, Elingerode	07/2011
Weihenstephan University of Applied Sciences	07/2011, 09/2011 10/2011
Forschungszentrum Juelich	07/2011
RWTH Aachen University	07/2011, 08/2011
INNEO Solutions, Ellwangen	06/2011
Caliqua, Basel, Switzerland	06/2011
Technical University of Freiberg	06/2011
Fichtner IT Consulting, Stuttgart	05/2011, 06/2011, 08/2011
Salzgitter Flachstahl, Salzgitter	05/2011
Helbling Beratung & Bauplanung, Zurich, Switzerland	05/2011
INEOS, Cologne	04/2011
Enseleit Consulting Engineers, Siebigerode	04/2011
Witt Consulting Engineers, Stade	03/2011
Helbling, Zurich, Switzerland	03/2011
MAN Diesel, Copenhagen, Denmark	03/2011
AGO, Kulmbach	03/2011
University of Duisburg	03/2011, 06/2011
CCP, Marburg	03/2011
BASF, Ludwigshafen	02/2011
ALSTOM Power, Baden, Switzerland	02/2011
Universität der Bundeswehr, Munich	02/2011
Calorifer, Elgg, Switzerland	01/2011
STRABAG, Vienna, Austria	01/2011
TUEV Sued, Munich	01/2011
ILK Dresden	01/2011
Technical University of Dresden	01/2011, 05/2011 06/2011, 08/2011

## 2010

Umweltinstitut Neumarkt	12/2010
YIT Austria, Vienna, Austria	12/2010
MCI Innsbruck, Austria	12/2010

University of Stuttgart	12/2010
HS Cooler, Wittenburg	12/2010
Visteon, Novi Jicin, Czech Republic	12/2010
CompuWave, Brunntal	12/2010
Stadtwerke Leipzig	12/2010
MCI Innsbruck, Austria	12/2010
EVONIK Energy Services, Zwingenberg	12/2010
Caliqua, Basel, Switzerland	11/2010
Shanghai New Energy Resources Science & Technology, China	11/2010
Energieversorgung Halle	11/2010
Hochschule für Technik Stuttgart, University of Applied Sciences	11/2010
Steinmueller, Berlin	11/2010
Amberg-Weiden University of Applied Sciences	11/2010
AREVA NP, Erlangen	10/2010
MAN Diesel, Augsburg	10/2010
KRONES, Neutraubling	10/2010
Vaillant, Remscheid	10/2010
PC Ware, Leipzig	10/2010
Schubert Consulting Engineers, Weißenberg	10/2010
Fraunhofer Institut UMSICHT, Oberhausen	10/2010
Behringer Consulting Engineers, Tagmersheim	09/2010
Saacke, Bremen	09/2010
WEBASTO, Neubrandenburg	09/2010
Concordia University, Montreal, Canada	09/2010
Compañía Eléctrica de Sochagota, Bogota, Colombia	08/2010
Hannover University of Applied Sciences	08/2010
ERGION, Mannheim	07/2010
Fichtner IT Consulting, Stuttgart	07/2010
TF Design, Matieland, South Africa	07/2010
MCE, Berlin	07/2010, 12/2010
IPM, Zittau/Goerlitz University of Applied Sciences	06/2010
TUEV Sued, Dresden	06/2010
RWE IT, Essen	06/2010
Glen Dimplex, Kulmbach	05/2010, 07/2010
	10/2010
Hot Rock, Karlsruhe	05/2010
Darmstadt University of Applied Sciences	05/2010
Voith, Heidenheim	04/2010
CombTec, Zittau	04/2010
University of Glasgow, Great Britain	04/2010
Universitaet der Bundeswehr, Munich	04/2010

Technical University of Hamburg-Harburg	04/2010
Vattenfall Europe, Berlin	04/2010
HUBER Consulting Engineers, Berching	04/2010
VER, Dresden	04/2010
CCP, Marburg	03/2010
Offenburg University of Applied Sciences	03/2010
Technical University of Berlin	03/2010
NIST Boulder CO, USA	03/2010
Technical University of Dresden	02/2010
Siemens Energy, Nuremberg	02/2010
Augsburg University of Applied Sciences	02/2010
ALSTOM Power, Baden, Switzerland	02/2010, 05/2010
MIT Massachusetts Institute of Technology Cambridge MA, USA	02/2010
Wieland Werke, Ulm	01/2010
Siemens Energy, Goerlitz	01/2010, 12/2010
Technical University of Freiberg	01/2010
ILK, Dresden	01/2010, 12/2010
Fischer-Uhrig Consulting Engineers, Berlin	01/2010

## 2009

ALSTOM Power, Baden, Schweiz	01/2009, 03/2009 05/2009
Nordostschweizerische Kraftwerke AG, Doettingen, Switzerland	02/2009
RWE, Neurath	02/2009
Brandenburg University of Technology, Cottbus	02/2009
Hamburg University of Applied Sciences	02/2009
Kehrein, Moers	03/2009
EPP Software, Marburg	03/2009
Bernd Münstermann, Telgte	03/2009
Suedzucker, Zeitz	03/2009
CPP, Marburg	03/2009
Gelsenkirchen University of Applied Sciences	04/2009
Regensburg University of Applied Sciences	05/2009
Gatley & Associates, Atlanta, USA	05/2009
BOSCH, Stuttgart	06/2009, 07/2009
Dr. Nickolay, Consulting Engineers, Gommersheim	06/2009
Ferrostal Power, Saarlouis	06/2009
BHR Bilfinger, Essen	06/2009
Intraserv, Wiesbaden	06/2009
Lausitz University of Applied Sciences, Senftenberg	06/2009
Nuernberg University of Applied Sciences	06/2009

Technical University of Berlin	06/2009
Fraunhofer Institut UMSICHT, Oberhausen	07/2009
Bischoff, Aurich	07/2009
Fichtner IT Consulting, Stuttgart	07/2009
Techsoft, Linz, Austria	08/2009
DLR, Stuttgart	08/2009
Wienstrom, Vienna, Austria	08/2009
RWTH Aachen University	09/2009
Vattenfall, Hamburg	10/2009
AIC, Chemnitz	10/2009
Midiplan, Bietigheim-Bissingen	11/2009
Institute of Air Handling and Refrigeration ILK, Dresden	11/2009
FZD, Rossendorf	11/2009
Techgroup, Ratingen	11/2009
Robert Sack, Heidelberg	11/2009
EC, Heidelberg	11/2009
MCI, Innsbruck, Austria	12/2009
Saacke, Bremen	12/2009
ENERKO, Aldenhoven	12/2009

## 2008

Pink, Langenwang	01/2008
Fischer-Uhrig, Berlin	01/2008
University of Karlsruhe	01/2008
MAAG, Kuesnacht, Switzerland	02/2008
M&M Turbine Technology, Bielefeld	02/2008
Lentjes, Ratingen	03/2008
Siemens Power Generation, Goerlitz	04/2008
Evonik, Zwingenberg (general EBSILON program license)	04/2008
WEBASTO, Neubrandenburg	04/2008
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,	07/2008
Professorship of Building Services	
Technical University of Cottbus,	07/2008, 10/2008
Chair in Power Plant Engineering	
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

## 2007

Audi, Ingolstadt	02/2007
ANO Abfallbehandlung Nord, Bremen	02/2007
TUEV NORD SysTec, Hamburg	02/2007
VER, Dresden	02/2007
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

## 2006

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,	02/2006
Department of Thermal Fluid Flow Engines	
Technical University of Munich,	02/2006
Chair in Apparatus and Plant Engineering	
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,	04/2006
Department of Thermodynamics	
EnviCon & Plant Engineering, Nuremberg	04/2006
Brassel Engineering, Dresden	05/2006
University of Halle-Merseburg,	05/2006
Department of USET Merseburg incorporated society	
Technical University of Dresden,	05/2006
Professorship of Thermic Energy Machines and Plants	
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	05/2006
Suedzucker, Ochsenfurt	06/2006
M&M Turbine Technology, Bielefeld	06/2006
Feistel Engineering, Volkach	07/2006
ThyssenKrupp Marine Systems, Kiel	07/2006

Caliqua, Basel, Switzerland (company license)	09/2006
Atlas-Stord, Rodovre, Denmark	09/2006
Konstanz University of Applied Sciences, Course of Studies Construction and Development	10/2006
Siemens Power Generation, Duisburg	10/2006
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	04/2005
Professorship of Thermic Energy Machines and Plants	
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
Redacom, Nidau, Switzerland	06/2005
Dumas Verfahrenstechnik, Hofheim	06/2005
Alensys Engineering, Erkner	07/2005
Stadtwerke Leipzig	07/2005
SaarEnergie, Saarbruecken	07/2005
ALSTOM ITC, Rugby, Great Britain	08/2005
Technical University of Cottbus, Chair in Power Plant Engineering	08/2005
Vattenfall Europe, Berlin (group license)	08/2005
Technical University of Berlin	10/2005
Basel University of Applied Sciences, Department of Mechanical Engineering, Switzerland	10/2005

Midiplan, Bietigheim-Bissingen	11/2005
Technical University of Freiberg, Chair in Hydrogeology	11/2005
STORA ENSO Sachsen, Eilenburg	12/2005
Energieversorgung Halle (company license)	12/2005
KEMA IEV, Dresden	12/2005

## 2004

Vattenfall Europe (group license)	01/2004
TUEV Nord, Hamburg	01/2004
University of Stuttgart, Institute of Thermodynamics and Heat Engineering	02/2004
MAN B&W Diesel A/S, Copenhagen, Denmark	02/2004
Siemens AG Power Generation, Erlangen	02/2004
Ulm University of Applied Sciences	03/2004
Visteon, Kerpen	03/2004, 10/2004
Technical University of Dresden,	
Professorship of Thermic Energy Machines and Plants	04/2004
Rerum Cognitio, Zwickau	04/2004
University of Saarbruecken	04/2004
Grenzebach BSH, Bad Hersfeld	04/2004
SOFBID Zwingenberg (general EBSILON program license)	04/2004
EnBW Energy Solutions, Stuttgart	05/2004
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
SorTech, Halle	11/2004
Enertech EUT, Radebeul (company license)	11/2004
Munich University of Applied Sciences	12/2004
STORA ENSO Sachsen, Eilenburg	12/2004
Technical University of Cottbus, Chair in Power Plant Engineering	12/2004
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
ALSTOM Power, Baden, Switzerland	01/2003, 07/2003
VER, Dresden	02/2003
Rietschle Energieplaner, Winterthur, Switzerland	02/2003
DLR, Leupholdhausen	04/2003
Emden University of Applied Sciences, Department of Technology	05/2003
Petterssson+Ahrends, Ober-Moerlen	05/2003
SOFBID ,Zwingenberg (general EBSILON program license)	05/2003
Ingenieurbuero Ostendorf, Gummersbach	05/2003
TUEV Nord, Hamburg	06/2003
Muenstermann GmbH, Telgte-Westbevern	06/2003
University of Cali, Colombia	07/2003
Atlas-Stord, Rodovre, Denmark	08/2003
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
Mainova, Frankfurt	12/2003
Energieversorgung Halle	12/2003

## 2002

Hamilton Medical AG, Rhaezuens, Switzerland	01/2002
Bochum University of Applied Sciences, Department of Thermo- and Fluid Dynamics	01/2002
SAAS, Possendorf/Dresden	02/2002
Siemens, Karlsruhe (general license for the WinIS information system)	02/2002

FZR Forschungszentrum, Rossendorf/Dresden	03/2002
CompAir, Simmern	03/2002
GKS Gemeinschaftskraftwerk, Schweinfurt	04/2002
ALSTOM Power Baden, Switzerland (group licenses)	05/2002
InfraServ, Gendorf	05/2002
SoftSolutions, Muehlhausen (company license)	05/2002
DREWAG, Dresden (company license)	05/2002
SOFBID, Zwingenberg	06/2002
(general EBSILON program license)	
Kleemann Engineering, Dresden	06/2002
Caliqua, Basel, Switzerland (company license)	07/2002
PCK Raffinerie, Schwedt (group license)	07/2002
Fischer-Uhrig Engineering, Berlin	08/2002
Fichtner Consulting & IT, Stuttgart	08/2002
(company licenses and distribution)	
Stadtwerke Duisburg	08/2002
Stadtwerke Hannover	09/2002
Siemens Power Generation, Goerlitz	10/2002
Energieversorgung Halle (company license)	10/2002
Bayer, Leverkusen	11/2002
Dillinger Huette, Dillingen	11/2002
G.U.N.T. Geraetebau, Barsbuettel	12/2002
(general license and training test benches)	
VEAG, Berlin (group license)	12/2002

## 2001

ALSTOM Power, Baden, Switzerland	01/2001, 06/2001 12/2001
KW2 B. V., Amersfoot, Netherlands	01/2001, 11/2001
Eco Design, Saitamaken, Japan	01/2001
M&M Turbine Technology, Bielefeld	01/2001, 09/2001
MVV Energie, Mannheim	02/2001
Technical University of Dresden, Department of Power Machinery and Plants	02/2001
PREUSSAG NOELL, Wuerzburg	03/2001
Fichtner Consulting & IT Stuttgart	04/2001
(company licenses and distribution)	
Muenstermann GmbH, Telgte-Westbevern	05/2001
SaarEnergie, Saarbruecken	05/2001
Siemens, Karlsruhe	08/2001
(general license for the WinIS information system)	
Neusiedler AG, Ulmerfeld, Austria	09/2001

h s energieranlagen, Freising	09/2001
Electrowatt-EKONO, Zurich, Switzerland	09/2001
IPM Zittau/Goerlitz University of Applied Sciences (general license)	10/2001
eta Energieberatung, Pfaffenhofen	11/2001
ALSTOM Power Baden, Switzerland	12/2001
VEAG, Berlin (group license)	12/2001

## 2000

SOFBID, Zwingenberg (general EBSILON program license)	01/2000
AG KKK - PGW Turbo, Leipzig	01/2000
PREUSSAG NOELL, Wuerzburg	01/2000
M&M Turbine Technology, Bielefeld	01/2000
IBR Engineering Reis, Nittendorf-Undorf	02/2000
GK, Hannover	03/2000
KRUPP-UHDE, Dortmund (company license)	03/2000
UMAG W. UDE, Husum	03/2000
VEAG, Berlin (group license)	03/2000
Thinius Engineering, Erkrath	04/2000
SaarEnergie, Saarbruecken	05/2000, 08/2000
DVO Data Processing Service, Oberhausen	05/2000
RWTH Aachen University	06/2000
VAUP Process Automation, Landau	08/2000
Knuerr-Lommatec, Lommatzsch	09/2000
AVACON, Helmstedt	10/2000
Compania Electrica, Bogota, Colombia	10/2000
G.U.N.T. Geraetebau, Barsbuettel (general license for training test benches)	11/2000
Steinhaus Informationssysteme, Datteln (general license for process data software)	12/2000

## 1999

Bayernwerk, Munich	01/1999
DREWAG, Dresden (company license)	02/1999
KEMA IEV, Dresden	03/1999
Regensburg University of Applied Sciences	04/1999
Fichtner Consulting & IT, Stuttgart (company licenses and distribution)	07/1999
Technical University of Cottbus, Chair in Power Plant Engineering	07/1999
Technical University of Graz, Department of Thermal Engineering, Austria	11/1999
Ostendorf Engineering, Gummersbach	12/1999

## 1998

Technical University of Cottbus, Chair in Power Plant Engineering	05/1998
Fichtner Consulting & IT (CADIS information systems) Stuttgart (general KPRO program license)	05/1998
M&M Turbine Technology Bielefeld	06/1998
B+H Software Engineering Stuttgart	08/1998
Alfa Engineering, Switzerland	09/1998
VEAG Berlin (group license)	09/1998
NUTEC Engineering, Bisikon, Switzerland	10/1998
SCA Hygiene Products, Munich	10/1998
RWE Energie, Neurath	10/1998
Wilhelmshaven University of Applied Sciences	10/1998
BASF, Ludwigshafen (group license)	11/1998
Energieversorgung, Offenbach	11/1998

**1997**

Gerb, Dresden	06/1997
Siemens Power Generation, Goerlitz	07/1997