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TECHNICAL THERMODYNAMICS

Property Library for Tetradecamethyl-hexasiloxane (MD4M) $C_{14}H_{42}O_5Si_6$

FluidDYM
with LibMD4M
for DYMOLA®

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Property Software for Tetradecamethylhexasiloxane

$C_{14}H_{42}Si_6O_5$ (LibMD4M)

FluidDYM

for DYMOLA®

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0. Package Contents

Zip-file "CD_FluidDYM_LibMD4M_Eng.zip" for DYMOLA®

Including the following files:

FluidDYM_LibMD4M_Setup.exe	Installation Program for the FluidDYM Add-In for use in DYMOLA®
LibMD4M.dll	Dynamic Link Library for Tetradecamethylhexasiloxane MD4M for use in DYMOLA®
FluidDYM_LibMD4M_Docu_Eng.pdf	User's Guide
Folder "Users_Guide"	Includes the complete User's Guide

1. Property Functions

1.1 Calculation Programs

“MD4M” means Tetradecamethylhexasiloxane ($C_{14}H_{42}O_5Si_6$)

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)
$\left(\frac{\partial p}{\partial T}\right)_v = f(p,t,x)$	dpdtv_ptx_MD4M	DPDTVMD4M(P,T,X)	C_DPDTVMD4M(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/(m³/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/m³
$s = f(p,t,x)$	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	m³/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°C to 399.85 °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 °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.

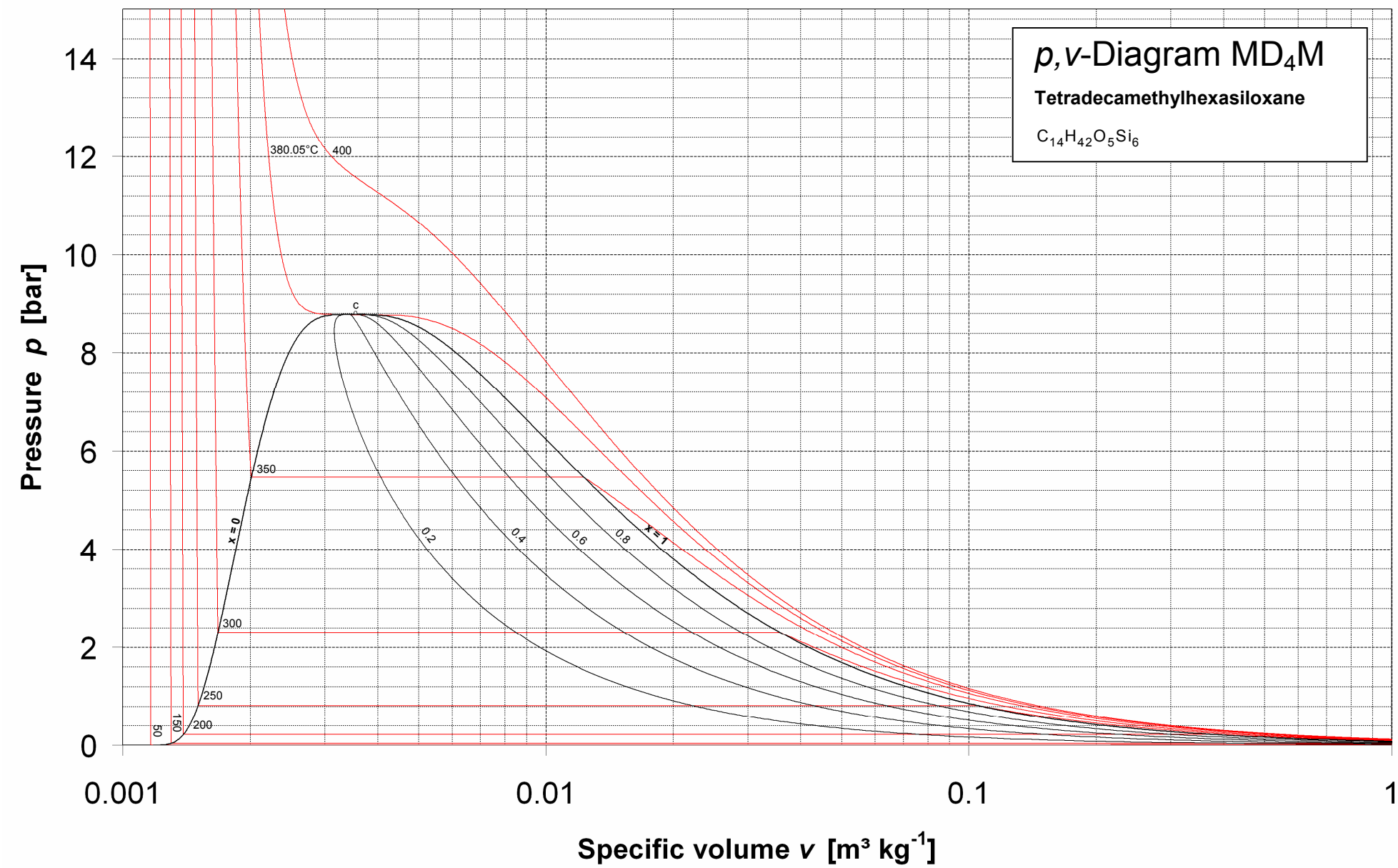
If *p* and *t* and *x* are entered as given values, the program considers *p* and *t* to be appropriate to represent the vapor pressure curve. If this is not the case the calculation for the property of the chosen function results in –1000.

Wet steam region: Temperature range from t = 26.85 °C to t_c = 379.05 °C
Pressure range from p_s (26.85 °C) = 0.00001093377 bar to p_c = 8.7747391 bar

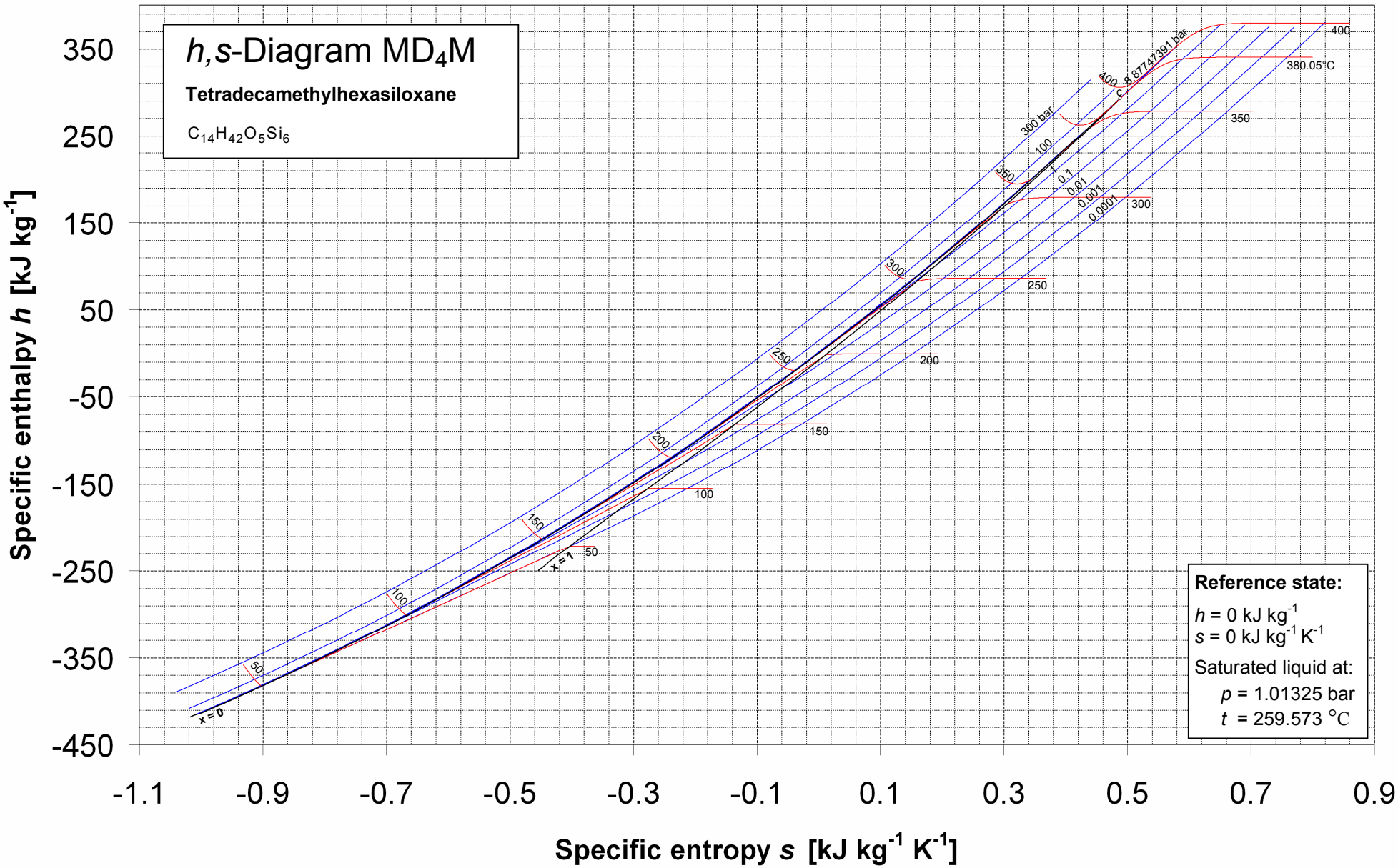
Note.

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.

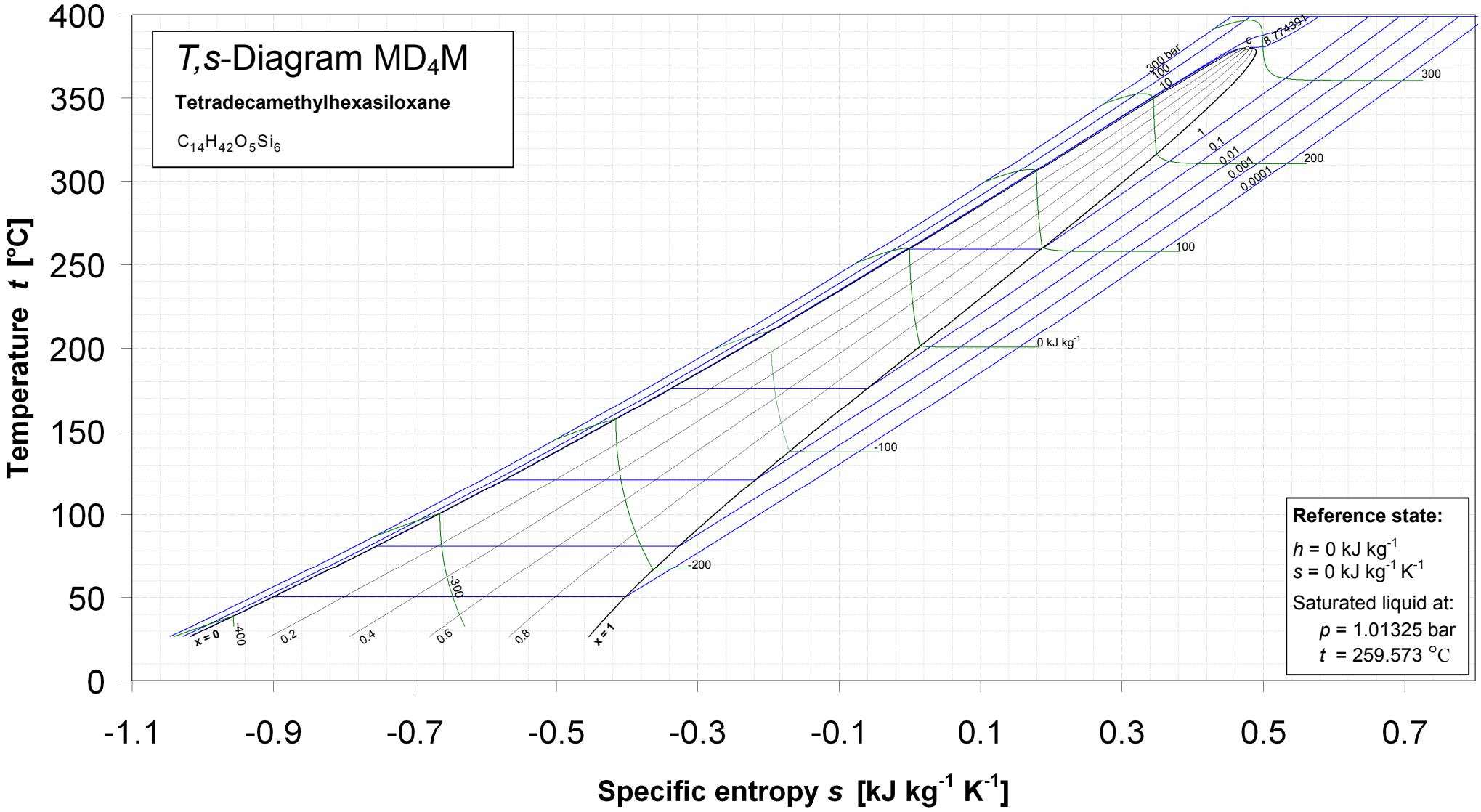
1.2 *p,v*-Diagram



1.3 *h,s*-Diagram



1.4 *T,s*-Diagram



2. Application of FluidDYM in Dymola®

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

2.1 Installing FluidDYM

FluidDYM will be installed by means of a self-extracting setup file. 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_FluidDYM_LibMD4M_Eng.zip", you will see the folder

CD_FluidDYM_LibMD4M_Eng

in your Windows Explorer®, Norton Commander® etc.

Now, open this folder by double-clicking on it.

Within this folder you will see the following files:

FluidDYM_LibMD4M_Docu_Eng.pdf
FluidDYM_LibMD4M_Setup.exe.

In order to run the installation of FluidDYM including the LibMD4M property library double-click the file

FluidDYM_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 "Continue" button.

In the following dialog box, "Choose Destination Location", the default path offered automatically for the installation of FluidDYM is
"C:\Program Files\FluidDYM\LibMD4M" (see Figure 2.1).

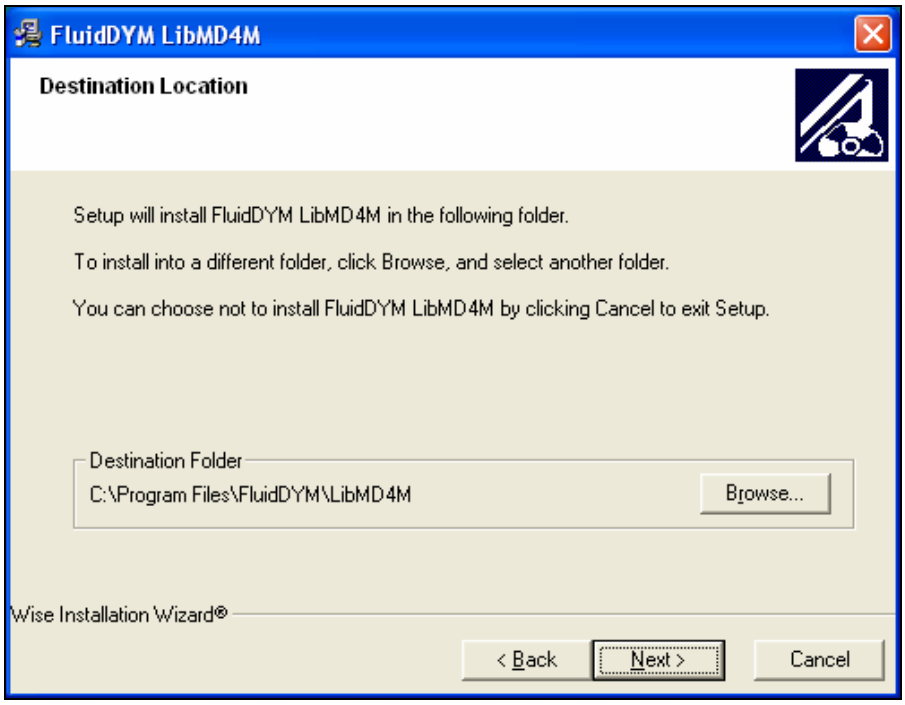


Figure 2.1: Dialog window "Destination Location"

By clicking the "Browse…" button, you can change the installation directory before installation. If you wish to change directory, click the "Browse…" button and select your desired directory. The instructions in this user's guide 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 the installation. The FluidDYM files are now being copied onto your hard disk drive into the created directory. Click the "Finish>" button in the following window to finish installation.

The installation program has copied the following files into the directory "C:\Program Files\FluidDYM\LibMD4M":

- Dynamic link library "LibMD4M.dll".

- Link up Dynamic link library "LibMD4M_Dym.dll" and other necessary system DLL files.

- Library File "LibMD4M_DYM.lib"

- Header File "LibMD4M_DYM.h" and other necessary system DLL files.

- Modelica File "FluidDYM_LibMD4M.mo", includes the following property 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 LibMD4M directory with the file of the same name provided in your CD folder with FluidDYM.
To do this, open the CD folder "CD_FluidDYM_LibMD4M_Eng" 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 LibMD4M directory (the standard being

C:\Program Files\FluidDYM\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.

In the next step, copy the folder "Users_Guide" into your Dymola LibMD4M directory with the file of the same name provided in your CD folder of FluidDYM.
To do this, open the CD folder "CD_FluidDYM_LibMD4M_Eng" in "My Computer" and click on the folder "Users_Guide" to highlight it. Then click on the "Edit" menu in your Explorer and select "Copy".

Now, open your Dymola LibMD4M directory (the standard being:

C:\Program Files\FluidDYM\LibMD4M)

and insert the folder "Users_Guide" by clicking the "Edit" menu in your Explorer and then selecting "Paste". Now, the folder "Users_Guide" has been successfully placed in your installation directory.

Licensing the LibMD4M Property Library

The licensing procedure has to be carried out when DYMOLA® is running and a model simulation starts. In this case, you will see the "License Information" window (see figure below).

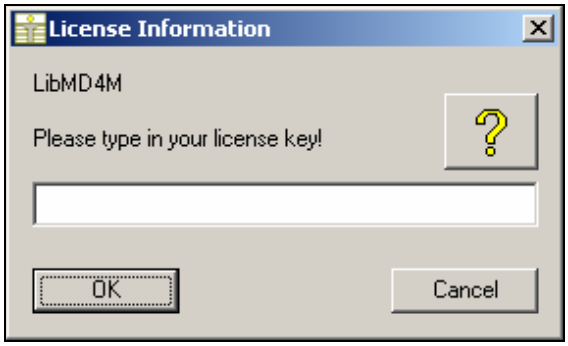


Figure 2.2: "License Information" window

Here you will have to type in the license key which you have obtained from the Zittau/Goerlitz University of Applied Sciences. You can find contact information on the "Content" page of this User's Guide or by clicking the yellow question mark in the "License Information" window. Then the following window will appear:

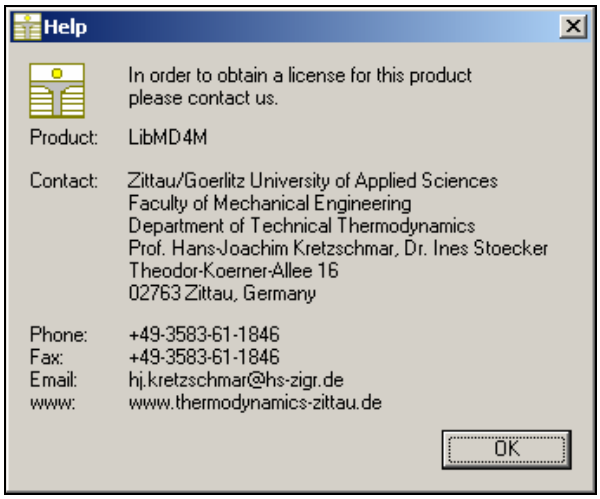


Figure 2.3: "Help" window

If you do not enter a valid license it is still possible to use DYMOLA® 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 start DYMOLA unless you uninstall FluidDYM_LibMD4M according to the description in section 2.3 of this User's Guide.
Should you not wish to license the LibMD4M property library, you have to delete the files

LibMD4M.dll
LibMD4M_DYM.dll
LibMD4M_DYM.lib
LibMD4M_DYM.h
LibMD4M_DYM.mo

in the installation folder of Dymola® (the standard being
C:\Program Files\FluidDYM)
using an appropriate program such as Explorer® or Norton Commander.

2.2 Example: Calculation of the Specific Enthalpy *h* = f(*p*,*t*,*x*) of Tetradecamethylhexasiloxane

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

Please carry out the following instructions:

- Start Windows Explorer®, Total Commander®, My Computer or another file manager program.
  The description here refers to Windows Explorer.
- Your Windows Explorer should be set to Details for a better view. Click the "View" (Ansicht) button and select "Details".
- Switch into the program directory of FluidDYM in which you will find the folder "\LibMD4M"; the standard location is: "C:\Program Files\FluidDYM\LibMD4M"
- Create the folder "\LibMD4M_Example" by clicking on "File" in the Explorer menu, then "New" in the menu which appears, and then selecting "Folder". Name the new folder "\LibMD4M_Example".
- You will see the following window:

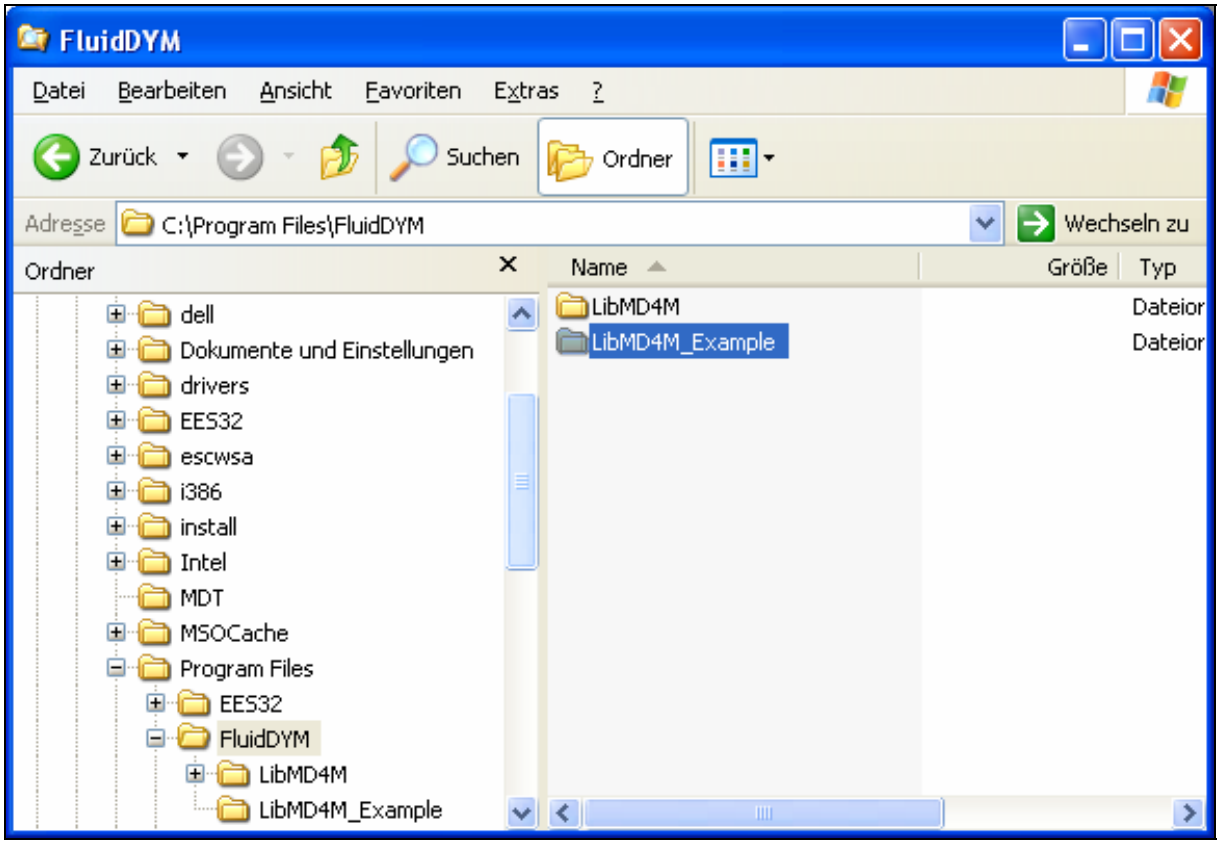


Figure 2.4: Highlighted *LibMD4M_Example* directory in FluidDYM

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

- You will see the following window:

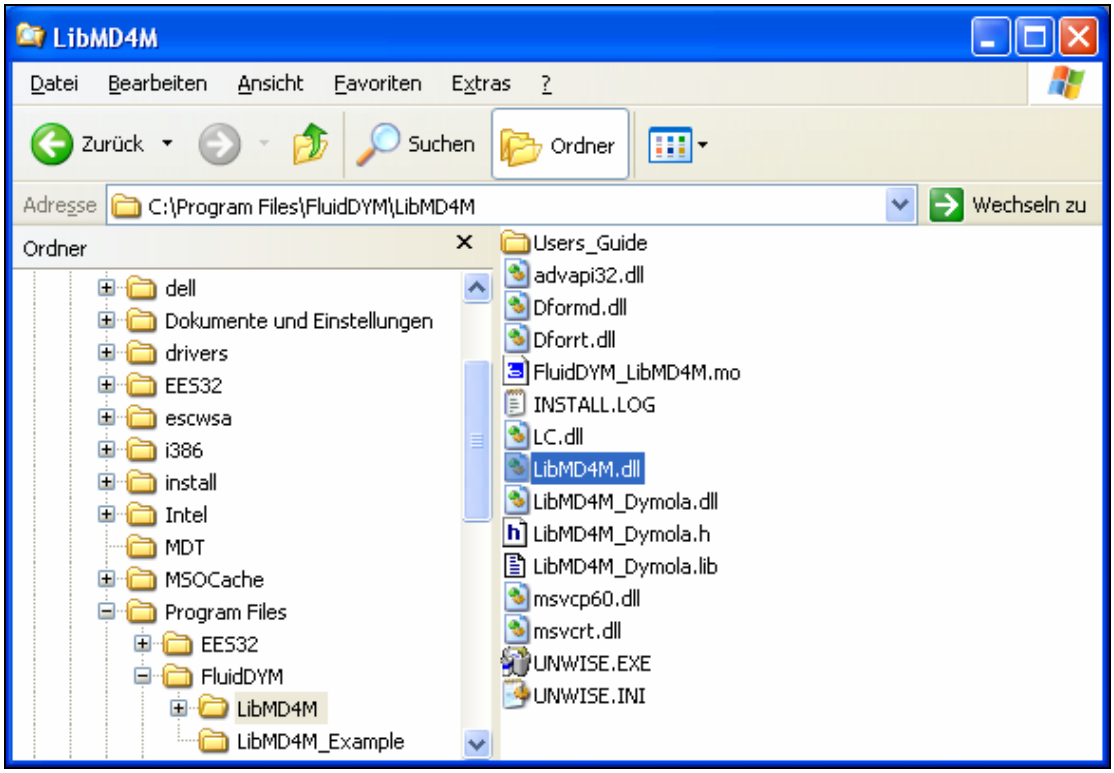


Figure 2.5: *LibMD4M* directory including installed files

In order to calculate the function $h = f(p,t,x)$, the following files are necessary. Copy them into the directory "C:\Program Files\FluidDYM\LibMD4M_Example":

- "advapi32.dll"
- "Dformd.dll"
- "Dforrt.dll"
- "FluidDYM_LibMD4M.mo"
- "LC.dll"
- "LibMD4M.dll"
- "LibMD4M_Dymola.dll"
- "LibMD4M_Dymola.h"
- "LibMD4M_Dymola.lib"
- "msvcp60.dll"
- "Msvcrt.dll"
- the folder "Users_Guide"

- Mark up these files, then click "Edit" in the upper menu bar and select "Copy".
- Switch into the directory "C:\Program Files\FluidDYM\LibMD4M_Example", click "Edit" and then "Paste".

- You will see the following window:

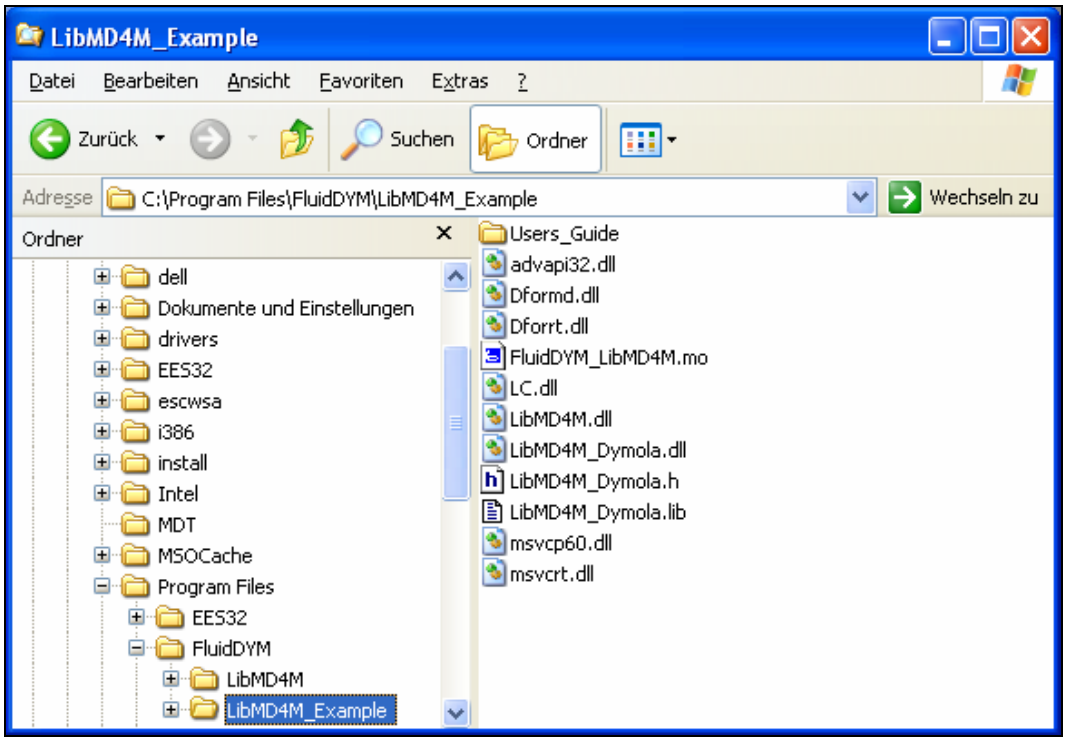


Figure 2.6: *LibMD4M_Example* directory including the newly-copied files

- Start Dymola®.
- Now click on "File" in the Dymola® menu bar and select "Open" (see Figure 2.7).

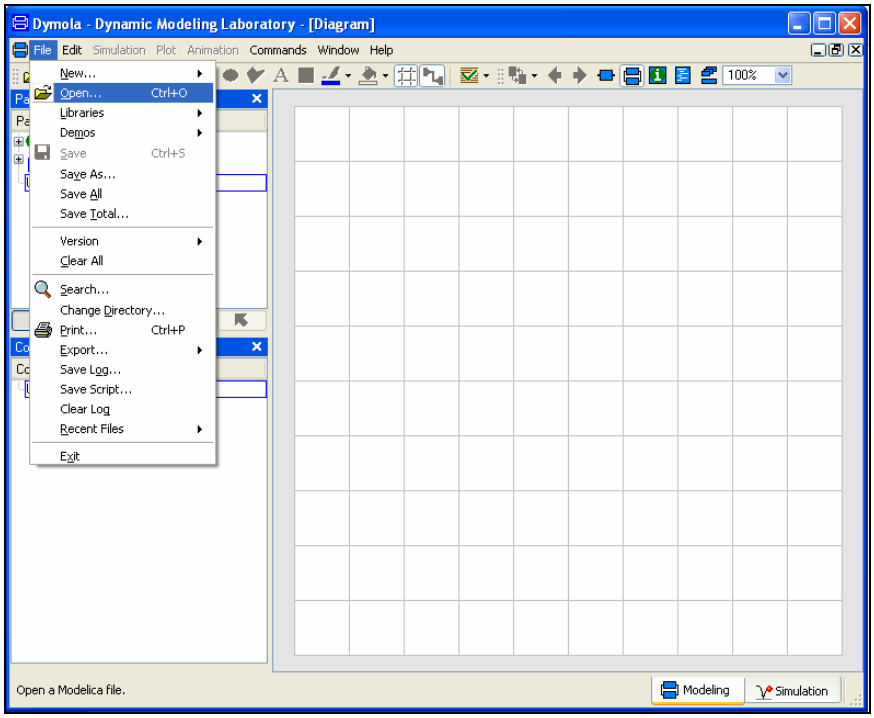


Figure 2.7: Selecting the menu entry "Open"

- Search and click on the directory "C:\Program Files\FluidDYM\LibMD4M_Example" in the menu that appears.

- Select the "FluidDYM_LibMD4M.mo" file and click on the "Open" button (see Figure 2.8).

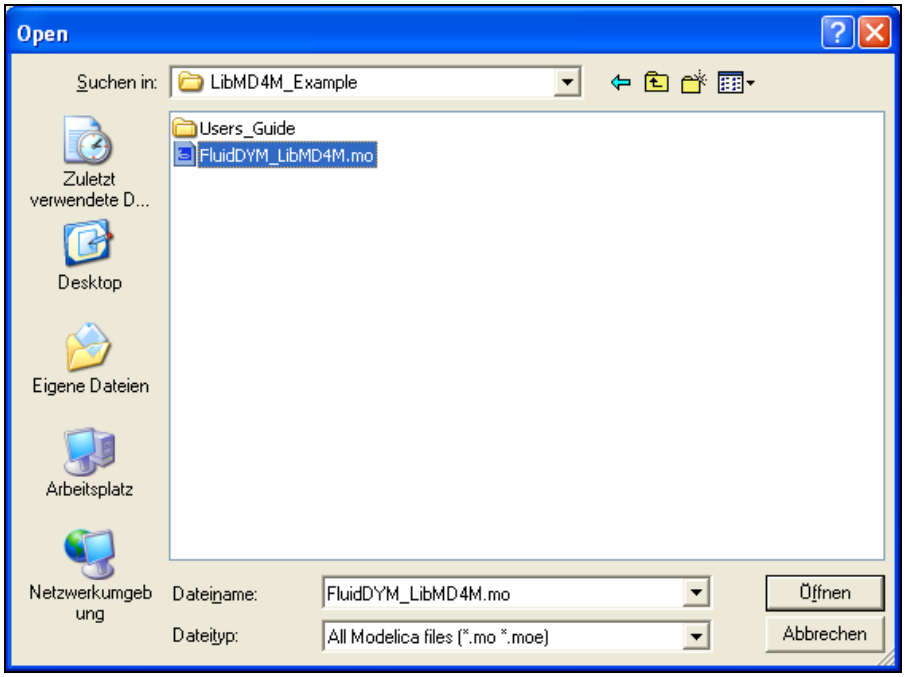


Figure 2.8: Selecting the *FluidDYM_LibMD4M.mo* file

- The library will be loaded by Dymola which may take a few seconds.
- After Dymola has finished loading the LibMD4M library, you will see the window shown in Figure 2.9.

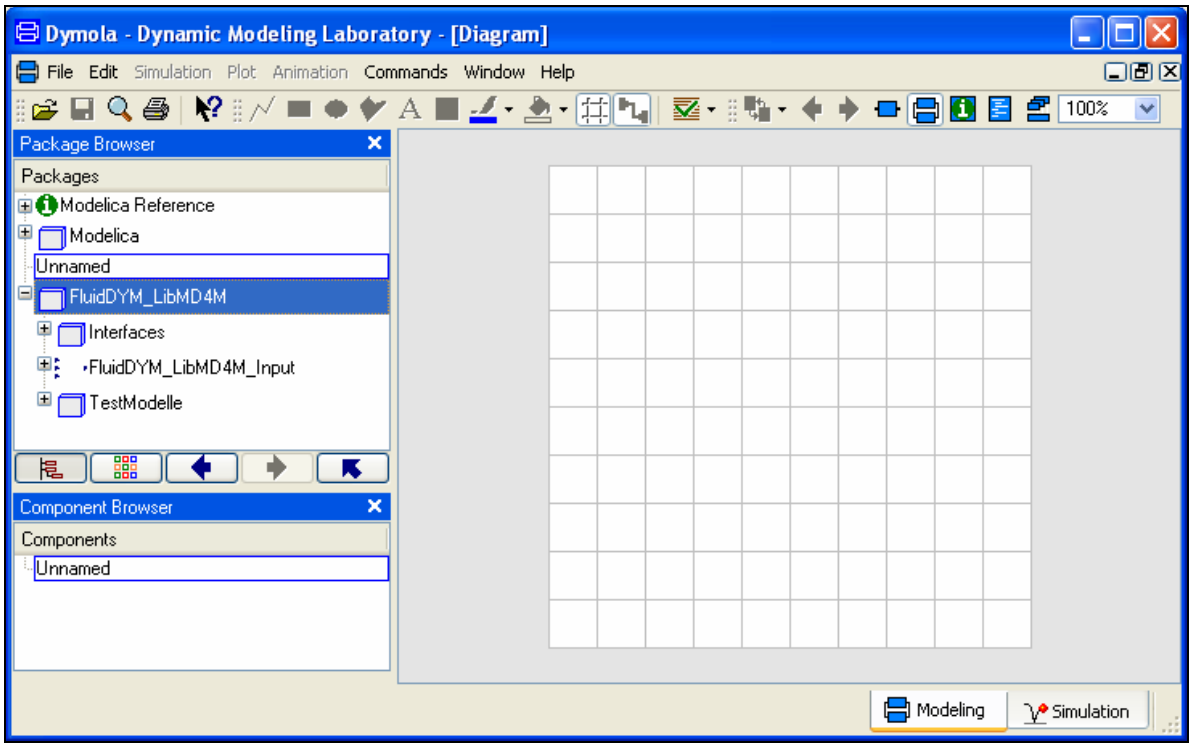


Figure 2.9: Dymola window after loading the *LibMD4M* library

- Now, click on "File" in the Dymola menu bar and select "Change Directory…" in order to open the folder "\LibMD4M_Example" (see Figure 2.10).

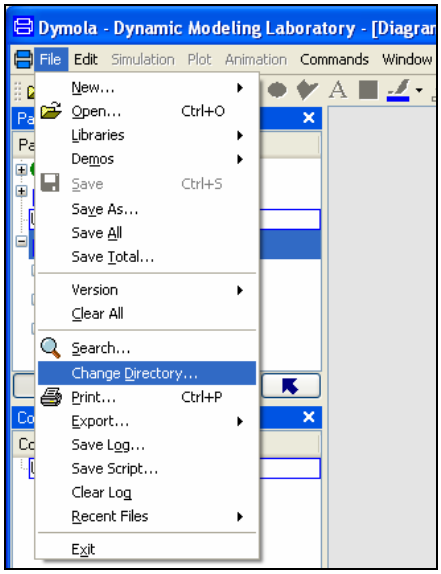


Figure 2.10: Selecting the menu entry "Change Directory…"

- Search and click on the directory "C:\Program Files\FluidDYM\LibMD4M_Example" in the menu that appears (see Figure 2.11).

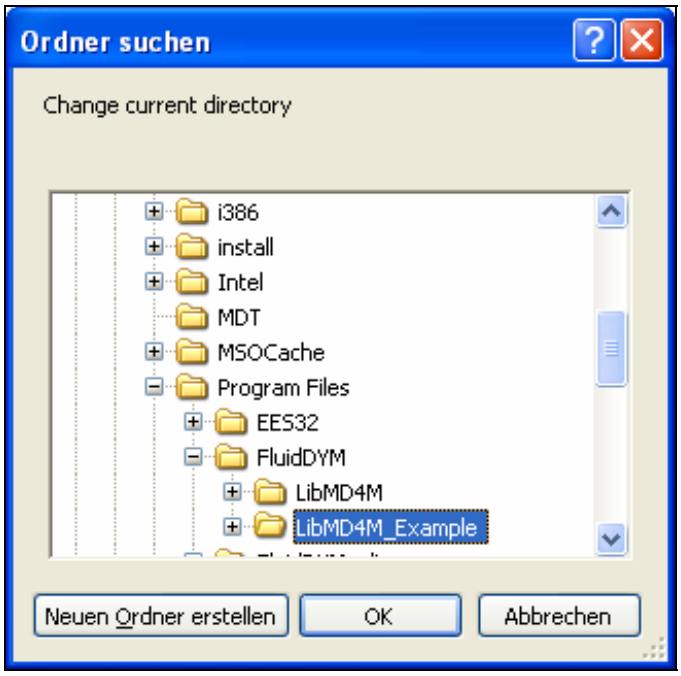


Figure 2.11: Selecting the *LibMD4M_Example* directory

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

As indicated in the table of property functions in Chapter 1, you have to call up the function "h_ptx_MD4M" as follows for calculating $h = f(p,t,x)$.

- Click on the Dymola-Block "Testmodelle," which can be found in the FluidDYM_LibMD4M package in the "Package Browser" on the left hand side of the Dymola window. Here choose Example1 by double-clicking on it.

- Now click on the button in the Dymola menu bar in order to switch to the Diagram

Mode. You will see the following window:

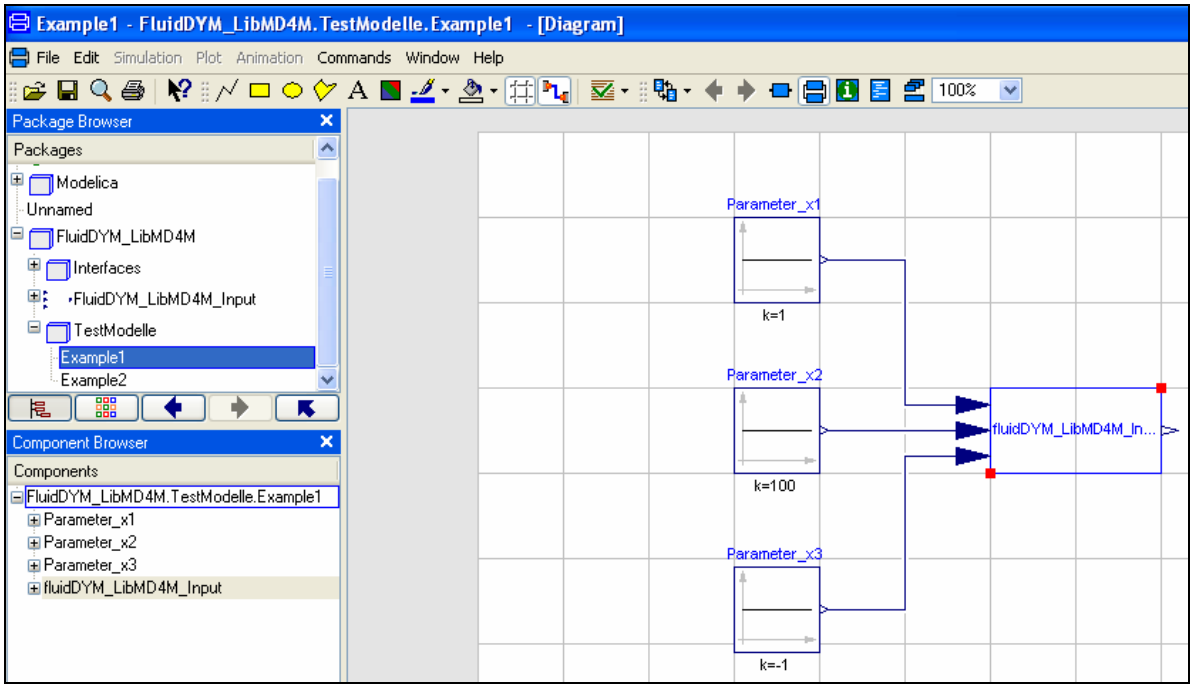


Figure 2.12: Dymola in Diagram Mode

- Now double-click on the "fluidDYM_LibMD4M_Input" block on the right hand side of the Dymola window.
- Search and click the "h_ptx_MD4M" function next to "Function Number" in the menu that appears (see Figure 2.13).

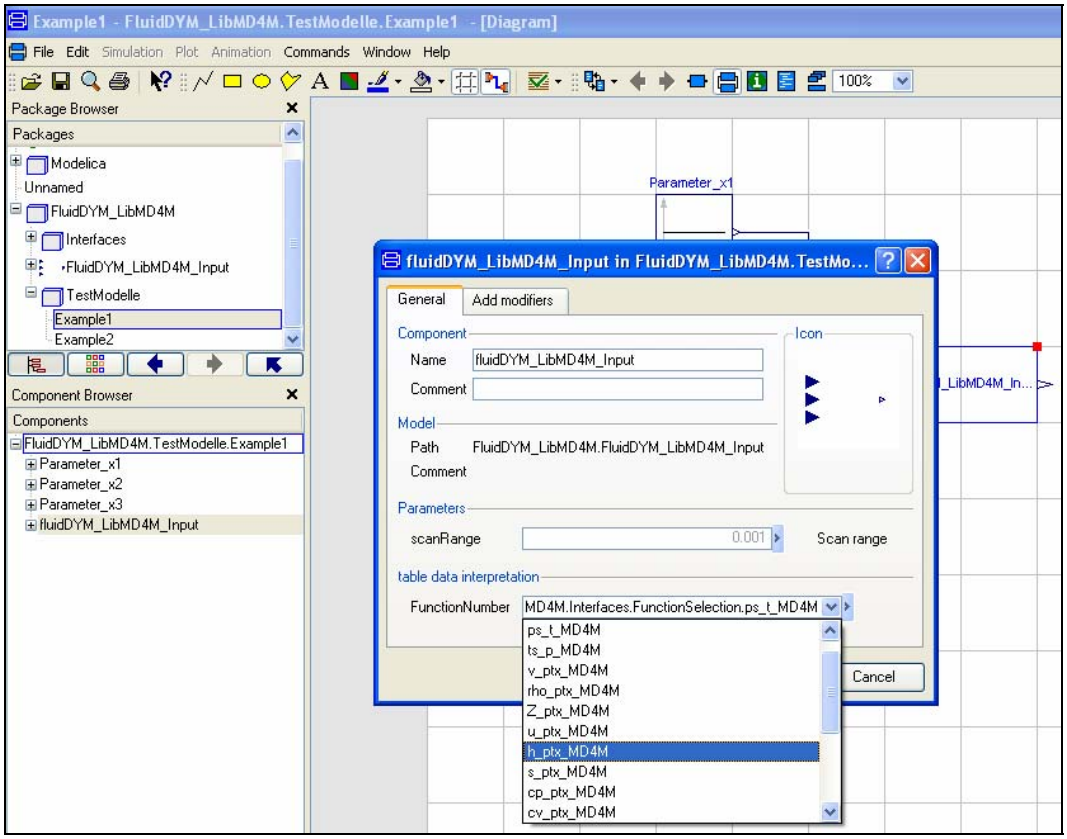


Figure 2.13: Choosing the function *h_ptx_MD4M*

- You can set the scan range (how many times the property will be calculated per second) next to "scanRange". The preset value 0.001 means that the property will be calculated 1000 times per second. E.g. if you enter the value 1, the property will be calculated once per second. Do not change the preset value of 0.001 for our example calculation.

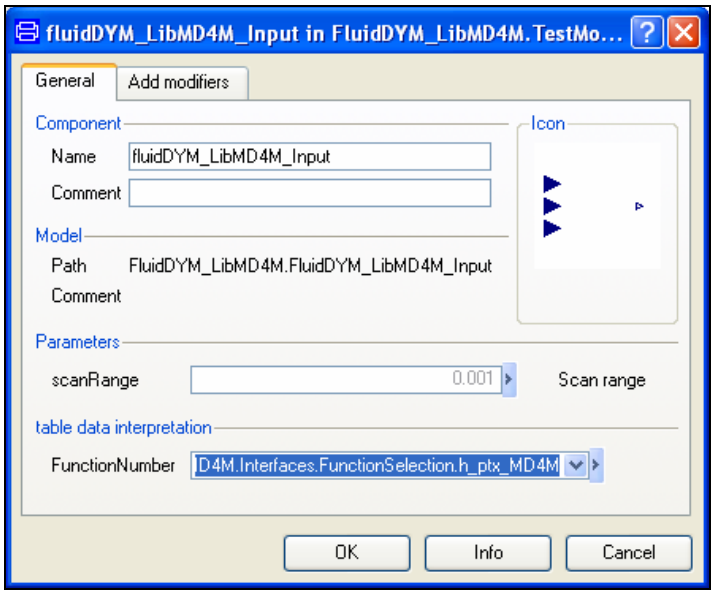


Figure 2.14: Setting the scan range

- Now we will configure the input parameters x1 to x3, where x1 represents the pressure *p*, x2 represents the temperature *t,* and x3 represents the vapor fraction *x*. When calculating a function with only two input parameters, the third input parameter x3 will not be defined.
- First, double click on the "Parameter_x1" block which represents the first input parameter, here the pressure *p* in bar.

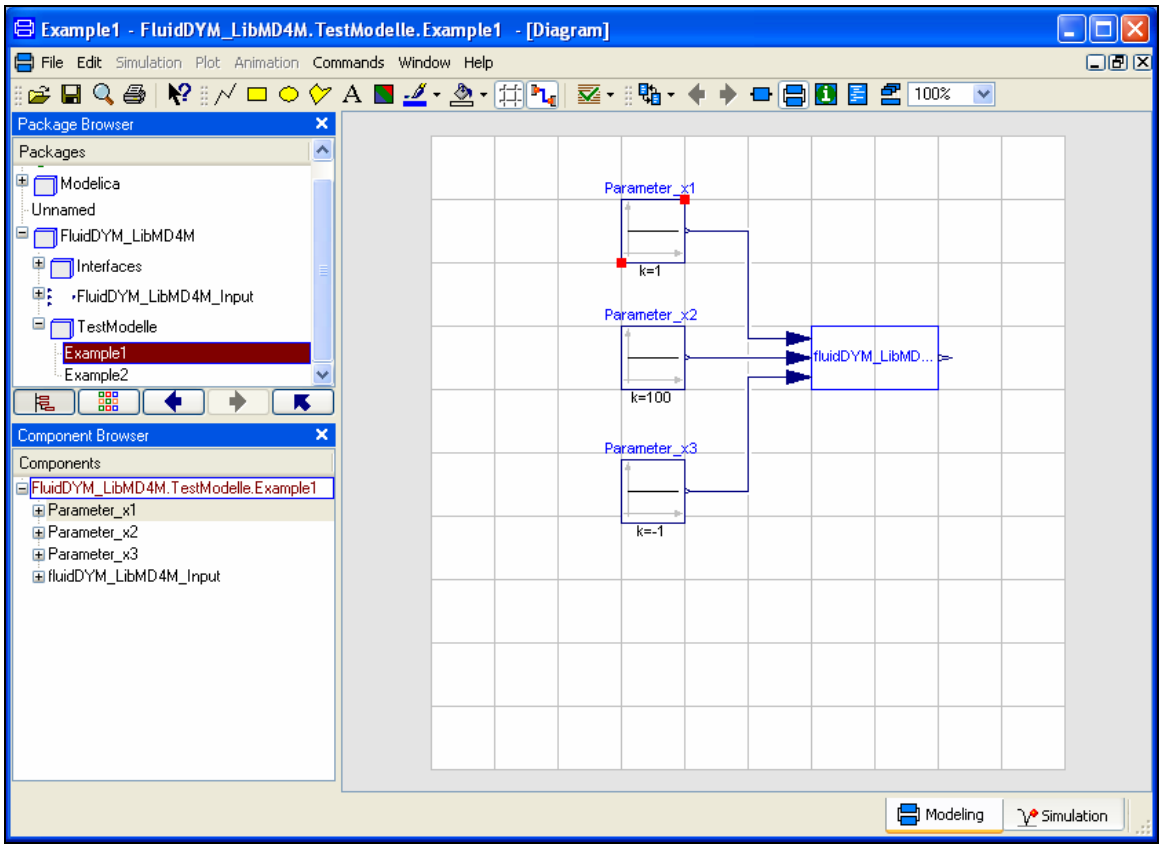


Figure 2.15: "Parameter_x1" block in Dymola

- Enter the value 10 on the line next to "k" in the dialog window which appears and then click the "OK" button (see Figure 2.16).

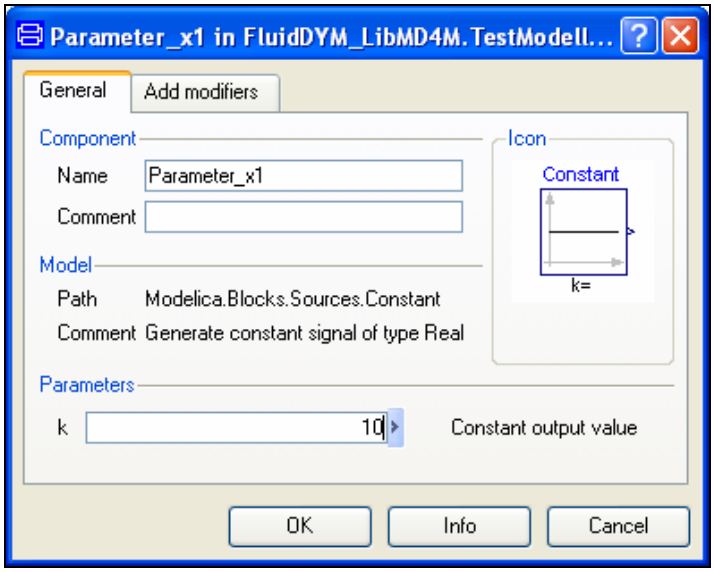


Figure 2.16: Entering the value for the pressure *p*

- Now, double click on the "Parameter_x2" block which represents the second input parameter, here the temperature *t* in °C.
- Enter the value 300 on the line next to "k" in the dialog window which appears and then click the "OK" button (see Figure 2.17).

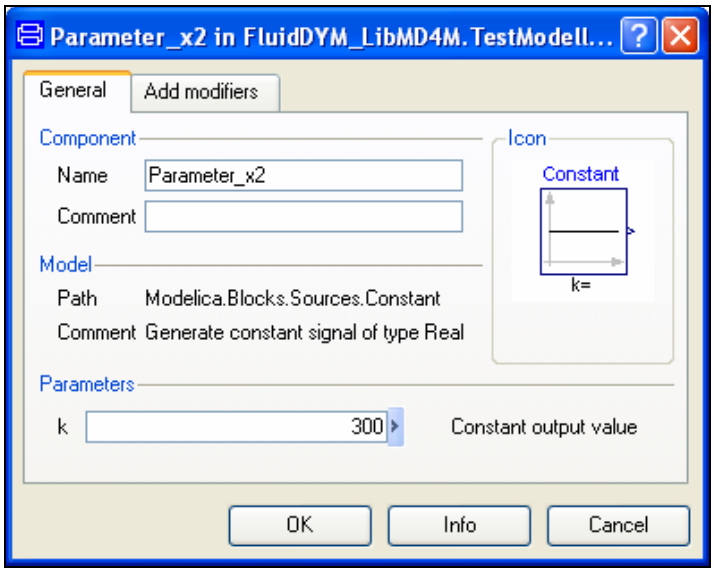


Figure 2.17: Entering the value for the temperature *t*

- Now, double click on the "Parameter_x3" block which represents the third input parameter, here the vapor fraction *x* in 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 °C to t_C = 379.05 °C

  p_S(26.85 °C) = 0.00001093377 bar to p_C = 8.7747391 bar)

- Enter the value -1 on the line next to "k" in the dialog window which appears and then click the "OK" button (see Figure 2.18).

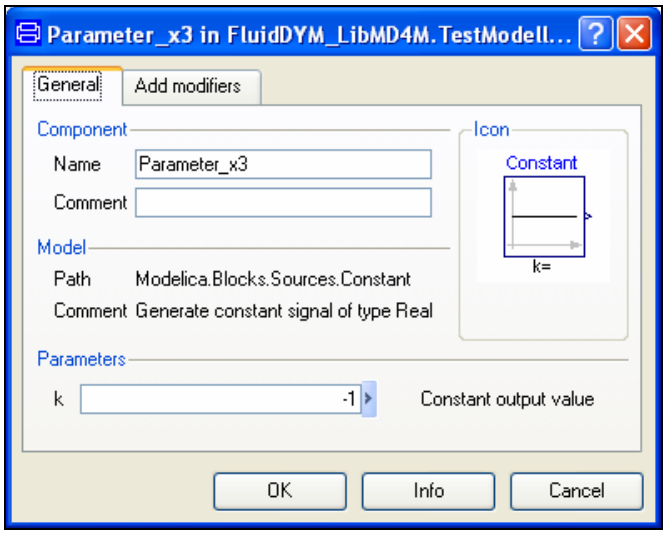


Figure 2.18: Entering the value for the vapor fraction *x*

All parameters have now been defined.

- Click on the Simulation button in the lower right area of Dymola in order to switch into the "Simulation Mode".

In Figure 2.19 you can see how the Dymola "Simulation Mode" looks like.

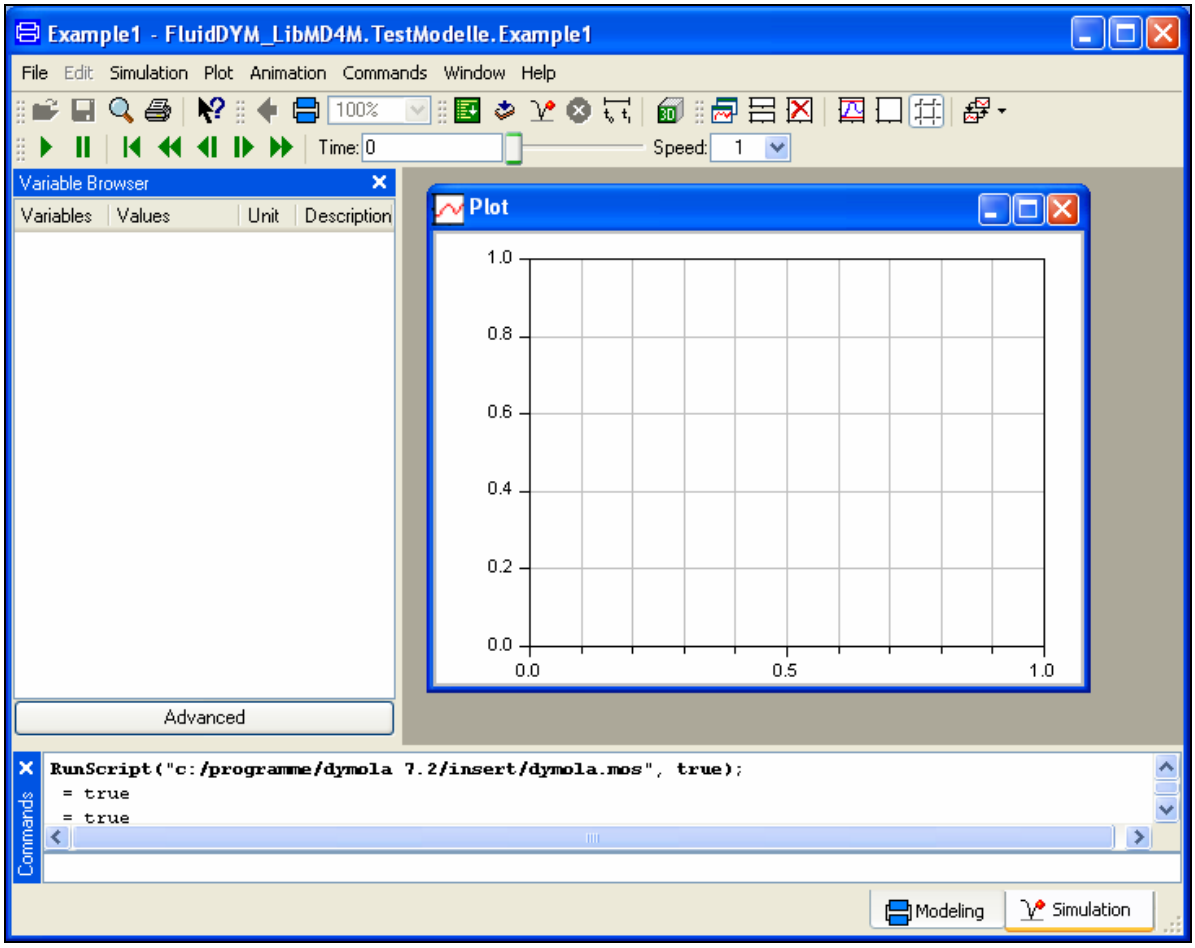


Figure 2.19: "Simulation Mode" window

- Click on the "Simulate" Button in the Dymola menu bar to start the calculation. Now the model will be compiled and the simulation started.
- Afterwards you will see the following entries within the "Variable Browser" window in Dymola (see Figure 2.20):

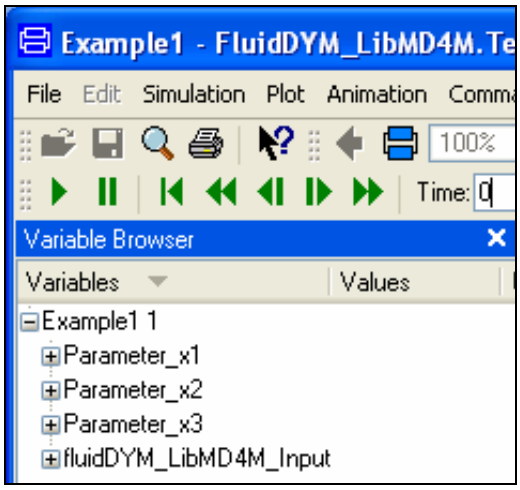


Figure 2.20: "Variable Browser" with new entries

- By clicking on the "New Plot Window" button , a new diagram window will be opened.
- Click on "fluidDYM_LibMD4M_Input" within the "Variable Browser"; then you will see the input and output parameters "scanRange", "FunctionNumber", "z", "x1", "x2" and "x3" (see Figure 2.21).

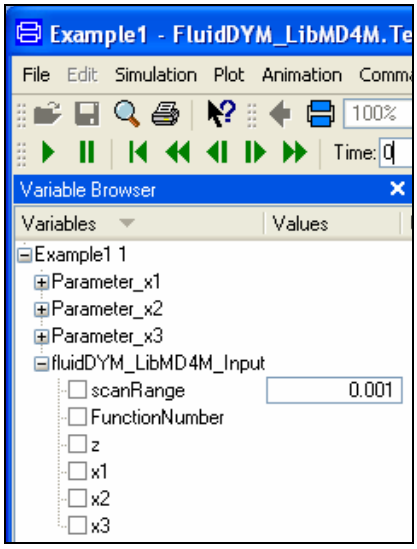


Figure 2.21: Parameters of *fluidDYM_LibMD4M_Input*

- After clicking on the output parameter "z", the calculated property will be represented graphically in the "PlotWindow".
- Move the mouse over the curve to see the result of the simulation at a specific point in time (see Figure 2.22).

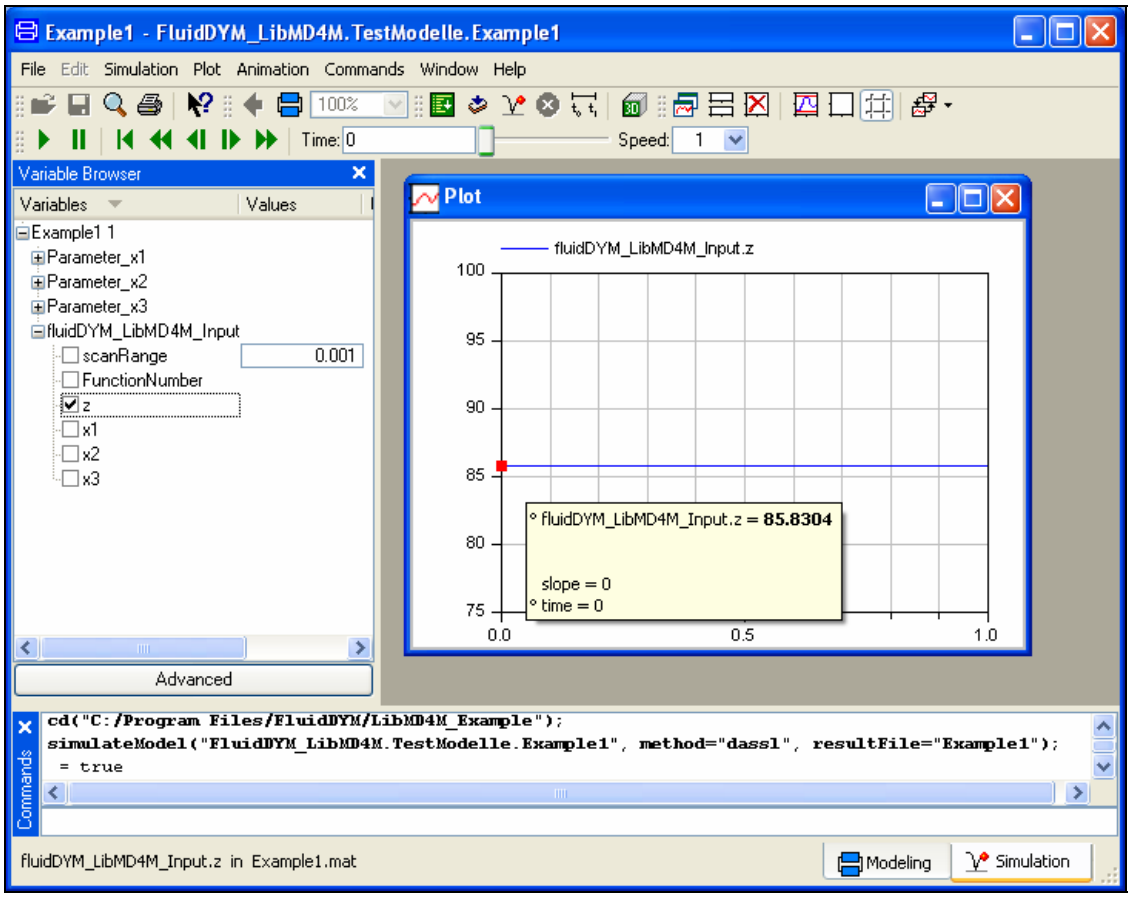


Figure 2.22: "DiagramWindow" showing the result

The result for *h* appears in the "DiagramWindow"

⇒ 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).

- Now click on the Modeling button

in the lower right area of Dymola in order to switch into the "Modeling Mode". Here you can arbitrarily change the values for *p*, *t*, or *x* in the appropriate blocks.

Help Systems in Dymola®

Dymola® provides detailed help functions. You can choose to read the program documentation or the help page of a specific property function, as desired.

Within the "Modeling-Mode"

the help may be accessed via two different steps.

First we will show you how to access the program documentation of the property library.

- Make sure Dymola is set to the "Modeling-Mode".
- Now click the button in the Dymola menu bar to choose the "Documentation Mode".
- Double-click on the "FluidDYM_LibMD4M" Block at the left and then click on "Users_Guide" (see Figure 2.23).

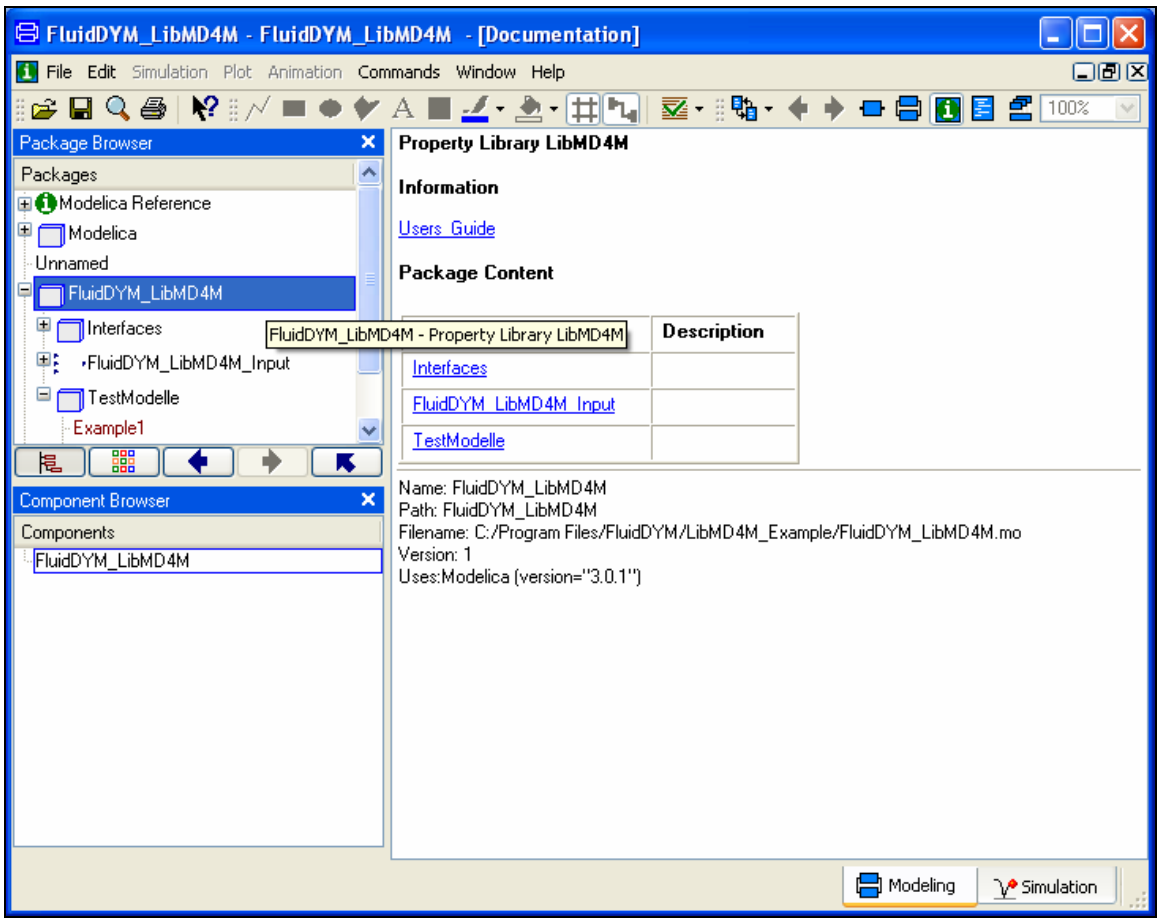


Figure 2.23: Selecting the "Users_Guide"

- The program documentation will be displayed within your default web browser.

Now, we will show you how to access the help page of a specific property function.

- Make sure Dymola is set to the "Modeling-Mode".
- Now click the button in the Dymola menu bar to choose the "Documentation Mode".
- Double-click on the "FluidDYM_LibMD4M_Input" block on the left (see Figure 2.24).

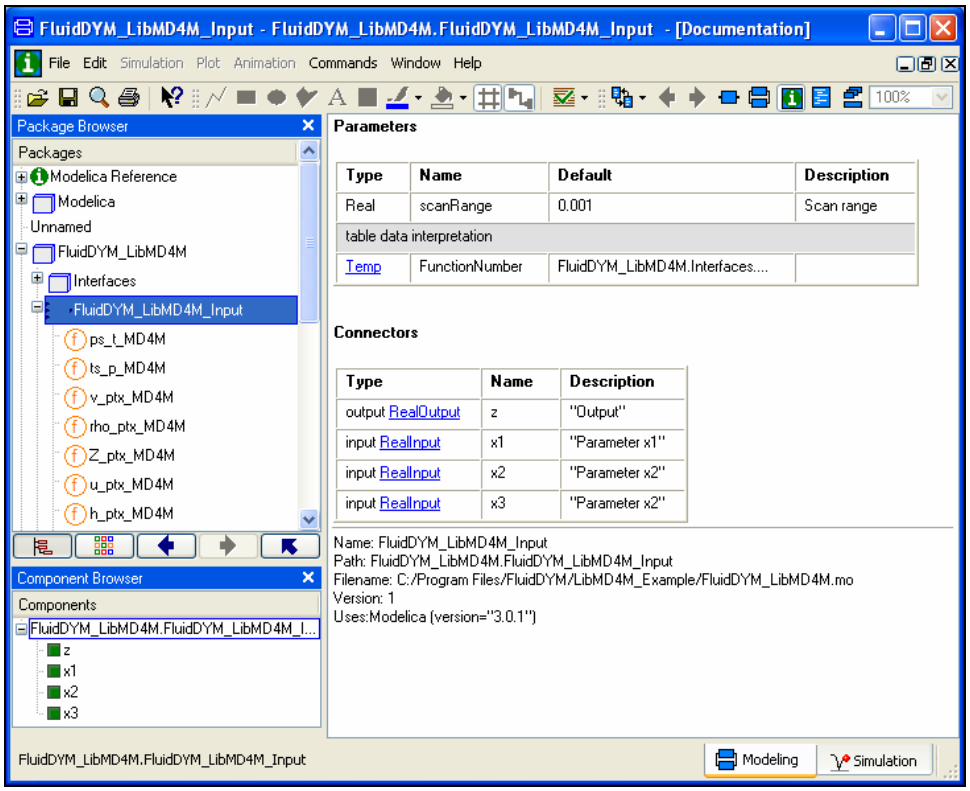


Figure 2.24: Selected "FluidDYM_LibMD4M_Input" Block

- Below "FluidDYM_LibMD4M_Input" you will see all functions of the LibMD4M property function (see Figure 2.24).
- Now select a function, e.g. "h_ptx_MD4M", and then click on "Users_Guide" (see Figure 2.25).

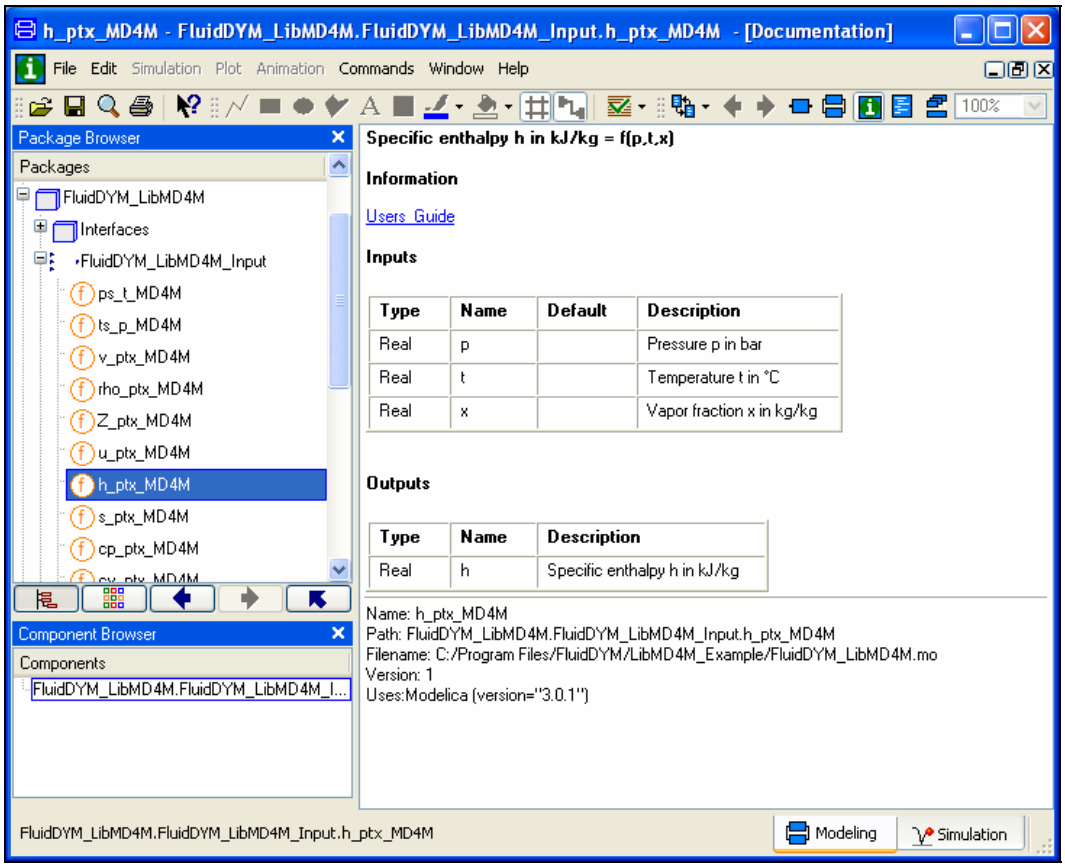


Figure 2.25: Marking the "h_ptx_MD4M" function and selecting the "Users_Guide"

- You will now see the help page of the selected function, here "h_ptx_MD4M", in your default web browser (see Figure 2.26).

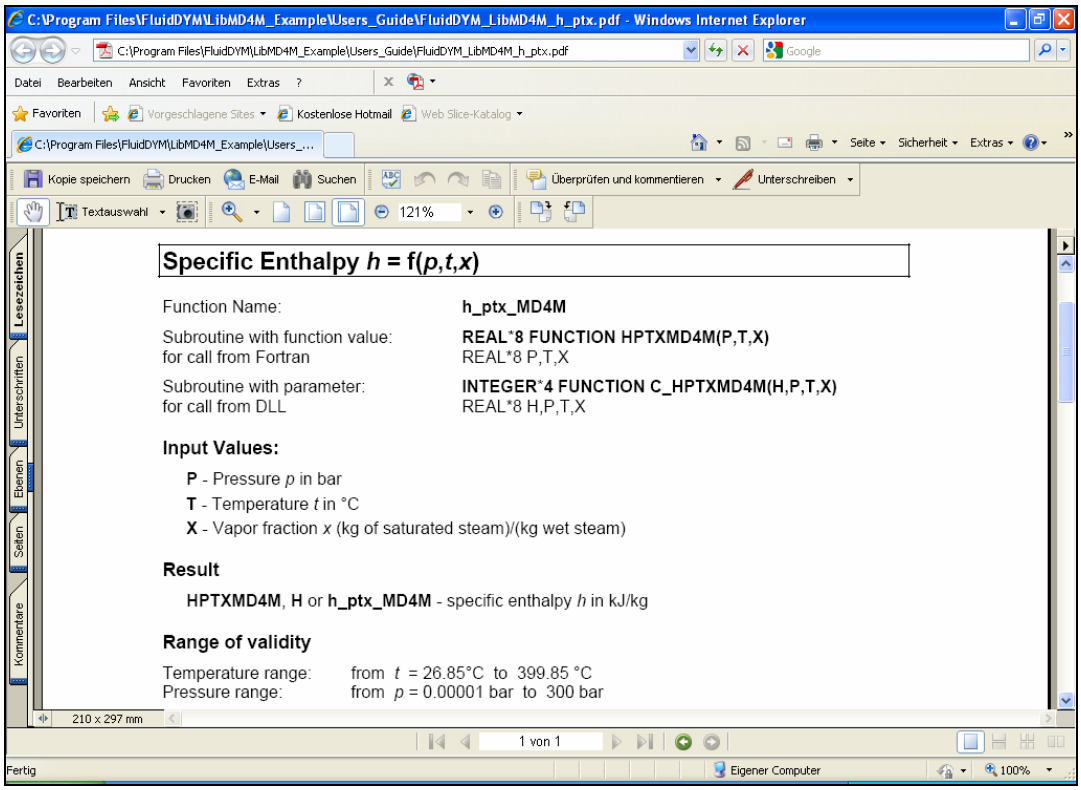


Figure 2.26: Help page of the function "h_ptx_MD4M" in the web browser

2.3 Removing LibMD4M in Dymola

In order to remove the property library LibMD4M from your hard drive in Windows®, click "Start" in the lower task bar, then "Settings" and "Control Panel".

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

In the list box of the "Add or Remove Programs" menu which appears, select "FluidDYM LibMD4M" by clicking on it and then clicking the "Change/Remove" button.

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

Confirm the "Perform Uninstall" menu which appears by clicking the "Finish" button.

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

"FluidDYM LibMD4M" has now been removed.

If LibMD4M is the only library installed, the directory "FluidDYM" will be removed as well.

3. Program Documentation

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

Function Name:	**cp_ptx_MD4M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION CPPTXMD4M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_CPPTXMD4M(CP,P,T,X)** REAL*8 CP,P,T,X

Input Values:

P - Pressure *p* in bar

T - Temperature *t* in °C

X - Vapor fraction *x* (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°C to 399.85 °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* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* (x = 0 or x = 1). If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the vapor pressure curve.

Saturated liquid and saturated vapor line:
Temperature ranges from $t = 26.85°C$ to $t_c = 379.05°C$
Pressure ranges from $p_s(26.85°C) = 0.00001093377$ 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: (x = -1)
p > 300 bar or p < 0.00001 bar or
t > 399.85 °C or t < 26.85°C

Saturation lines:
at p = -1000 and $t > t_c$ = 379.05 °C or t < 26.85 °C
at t = -1000 and $p > p_c$ = 8.7747391 bar
or $p < p_s$(26.85°C) = 0.00001093377 bar or
at $p > p_c$ = 8.7747391 bar or $p < p_s$(26.85°C) = 0.00001093377 bar and
$t > t_c$ = 379.05 °C or t < 26.85°C

References: [1]

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

Function Name:	**cv_ptx_MD4M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION CVPTXMD4M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_CVPTXMD4M(CV,P,T,X)** REAL*8 CV,P,T,X

Input Values:

P - Pressure p in bar

T - Temperature t in °C

X - Vapor fraction x (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°C to 399.85 °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 <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x (x = 0 or x = 1). If p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Saturated liquid and saturated vapor line: Temperature ranges from $t = 26.85°C$ to $t_c = 379.05°C$
Pressure ranges from $p_s(26.85°C) = 0.00001093377$ 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: (x = -1)
p > 300 bar or p < 0.00001 bar or
t > 399.85 °C or t < 26.85°C

Saturation lines:
at p = -1000 and $t > t_c$ = 379.05 °C or t < 26.85 °C
at t = -1000 and $p > p_c$ = 8.7747391 bar
or $p < p_s(26.85°C)$ = 0.00001093377 bar or
at $p > p_c$ = 8.7747391 bar or $p < p_s(26.85°C)$ = 0.00001093377 bar and
$t > t_c$ = 379.05 °C or t < 26.85°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:	**dpdtv_ptx_MD4M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION DPDTVPTXMD4M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_DPDTVPTXMD4M(DPDTV,P,T,X)** 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 **dpdtv_ptx_MD4M** - Derivative of pressure with respect to temperature (at constant specific volume) dpdtv in kPa/K

Range of validity

Temperature range: from t = 26.85°C to 399.85 °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* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* (x = 0 or x = 1). If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the vapor pressure curve.

Saturated liquid and saturated vapor line: Temperature ranges from $t = 26.85°C$ to $t_c = 379.05°C$
Pressure ranges from $p_s(26.85°C) = 0.00001093377$ bar to $p_c = 8.7747391$ bar

Results for wrong input values

Result **DPDTVPTXMD4M = -1000**, **DPDTV = -1000** or **dpdtvo_ptx_MD4M = -1000** for input values:

Single phase region: (x = -1)
p > 300 bar or p < 0.00001 bar or
t > 399.85 °C or t < 26.85°C

Saturation lines:
at p = -1000 and $t > t_c$ = 379.05 °C or t < 26.85 °C
at t = -1000 and $p > p_c$ = 8.7747391 bar
or $p < p_s$(26.85°C) = 0.00001093377 bar or
at $p > p_c$ = 8.7747391 bar or $p < p_s$(26.85°C) = 0.00001093377 bar and
$t > t_c$ = 379.05 °C or t < 26.85°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: for call from Fortran	**REAL*8 FUNCTION DPDVTPTXMD4M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_DPDVTPTXMD4M(DPDVT,P,T,X)** 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°C to 399.85 °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* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* (x = 0 or x = 1). If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the vapor pressure curve.

Saturated liquid and saturated vapor line: Temperature ranges from $t = 26.85°C$ to $t_c = 379.05°C$
Pressure ranges from $p_s(26.85°C) = 0.00001093377$ 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: (x = -1)
p > 300 bar or p < 0.00001 bar or
t > 399.85 °C or t < 26.85°C

Saturation lines:
at p = -1000 and $t > t_c$ = 379.05 °C or t < 26.85 °C
at t = -1000 and $p > p_c$ = 8.7747391 bar
or $p < p_s$(26.85°C) = 0.00001093377 bar or
at $p > p_c$ = 8.7747391 bar or $p < p_s$(26.85°C) = 0.00001093377 bar and
$t > t_c$ = 379.05 °C or t < 26.85°C

References: [1]

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

Function Name:	**h_ptx_MD4M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION HPTXMD4M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_HPTXMD4M(H,P,T,X)** REAL*8 H,P,T,X

Input Values:

P - Pressure *p* in bar

T - Temperature *t* in °C

X - Vapor fraction *x* (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°C to 399.85 °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* <u>and</u> p = -1000 or the given value for *p* <u>and</u> t = -1000 and in both cases the value for *x* between 0 and 1 must be entered.

If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program considers *p* and *t* to be appropriate to represent the vapor pressure curve.

Wet steam region: Temperature ranges from $t = 26.85°C$ to $t_c = 379.05°C$
Pressure ranges from $p_s(26.85°C) = 0.00001093377$ 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: (x = -1)
p > 300 bar or p < 0.00001 bar or
t > 399.85 °C or t < 26.85°C

Wet steam region:
at p = -1000 and $t > t_c$ = 379.05 °C or t < 26.85 °C
at t = -1000 and $p > p_c$ = 8.7747391 bar
or $p < p_s$(26.85°C) = 0.00001093377 bar or
at $p > p_c$ = 8.7747391 bar or $p < p_s$(26.85°C) = 0.00001093377 bar and
$t > t_c$ = 379.05 °C or t < 26.85°C

References: [1]

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

Function Name:	**kappa_ptx_MD4M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION KAPPAPTXMD4M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_KAPPAPTXMD4M(KAPPA, P,T,X)** 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°C to 399.85 °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* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* (x = 0 or x = 1). If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the vapor pressure curve.

Saturated liquid and saturated vapor line:	Temperature ranges from $t = 26.85°C$ to $t_c = 379.05°C$ Pressure ranges from $p_s(26.85°C) = 0.00001093377$ 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: (x = -1)	p > 300 bar or p < 0.00001 bar or t > 399.85 °C or t < 26.85°C
Saturation lines:	at p = -1000 and $t > t_c$ = 379.05 °C or t < 26.85 °C at t = -1000 and $p > p_c$ = 8.7747391 bar or $p < p_s(26.85°C)$ = 0.00001093377 bar or at $p > p_c$ = 8.7747391 bar or $p < p_s(26.85°C)$ = 0.00001093377 bar and $t > t_c$ = 379.05 °C or t < 26.85°C

References: [1]

Vapor Pressure p_s = f(t)

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

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 $t = 26.85$°C to $t_c = 379.05$ °C

Results for wrong input values

Result **PSTMD4M = -1000**, **PS = -1000**or **ps_t_MD4M = -1000**for input values:

$t < 26.85$°C or $t > t_c = 379.05$ °C

References: [1]

Density ρ = f(p,t,x)

Function Name:	**rho_ptx_MD4M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION RHOPTXMD4M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_RHOPTXMD4M(RHO,P,T,X)** REAL*8 RHO,P,T,X

Input Values:

P - Pressure p in bar

T - Temperature t in °C

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

Result

RHO_PTX_MD4M, **RHO** or **rho_ptx_MD4M** - Density ρ in kg/m^3

Range of validity

Temperature range: from t = 26.85°C to 399.85 °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 <u>and</u> p = -1000 or the given value for p <u>and</u> t = -1000 and in both cases the value for x between 0 and 1 must be entered.

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

Wet steam region: Temperature ranges from $t = 26.85°C$ to $t_c = 379.05°C$
Pressure ranges from $p_s(26.85°C) = 0.00001093377$ 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: (x = -1)
p > 300 bar or p < 0.00001 bar or
t > 399.85 °C or t < 26.85°C

Wet steam region:
at p = -1000 and $t > t_c$ = 379.05 °C or t < 26.85 °C
at t = -1000 and $p > p_c$ = 8.7747391 bar
or $p < p_s$(26.85°C) = 0.00001093377 bar or
at $p > p_c$ = 8.7747391 bar or $p < p_s$(26.85°C) = 0.00001093377 bar and
$t > t_c$ = 379.05 °C or t < 26.85°C

References: [1]

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

Function Name:	**s_ptx_MD4M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION SPTXMD4M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_SPTXMD4M(S,P,T,X)** REAL*8 S,P,T,X

Input Values:

P - Pressure *p* in bar

T - Temperature *t* in °C

X - Vapor fraction *x* (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°C to 399.85 °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* <u>and</u> p = -1000 or the given value for *p* <u>and</u> t = -1000 and in both cases the value for *x* between 0 and 1 must be entered.

If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program considers *p* and *t* to be appropriate to represent the vapor pressure curve.

Wet steam region: Temperature ranges from $t = 26.85°C$ to $t_c = 379.05°C$
Pressure ranges from $p_s(26.85°C) = 0.00001093377$ 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: (x = -1)
p > 300 bar or p < 0.00001 bar or
t > 399.85 °C or t < 26.85°C

Wet steam region:
at p = -1000 and $t > t_c$ = 379.05 °C or t < 26.85 °C
at t = -1000 and $p > p_c$ = 8.7747391 bar
or $p < p_s$(26.85°C) = 0.00001093377 bar or
at $p > p_c$ = 8.7747391 bar or $p < p_s$(26.85°C) = 0.00001093377 bar and
$t > t_c$ = 379.05 °C or t < 26.85°C

References: [1]

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

Function Name:	**t_ph_MD4M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION TPHMD4M(P,H)** REAL*8 P,H
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_TPHMD4M(T,P,H)** 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°C to 399.85 °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 $p_S(26.85°C) = 0.00001093377$ 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°C) = 0.00001093377 bar or
(x = -1) at result t > 399.85 °C, t < 26.85°C

Boiling or dew curve: at $p > p_C$ = 8.7747391 bar or $p < p_S$ 26.85°C = 0.00001093377 bar
at result $t > t_C$ = 379.05 °C or t < 26.85 °C

References: [1]

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

Function Name:	**t_ps_MD4M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION TPSMD4M(P,S)** REAL*8 P,S
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_TPSMD4M(T,P,S)** 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°C to 399.85 °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 $p_S(26.85°C) = 0.00001093377$ 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: (x = -1)	at p > 300 bar or $p < p_S$(26.85°C) = 0.00001093377 bar or at result t > 399.85 °C, t < 26.85°C
Boiling or dew curve:	at $p > p_C$ = 8.7747391 bar or $p < p_S$ 26.85°C = 0.00001093377 bar at result $t > t_C$ = 379.05 °C or t < 26.85 °C

References: [1]

Saturation Temperature t_s = f(p)

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

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 $p_s(26.85°C) = 0.00001093377$ 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:

$p < p_s(26.85°C) = 0.00001093377$ 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: for call from Fortran	**REAL*8 FUNCTION UPTXMD4M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_UPTXMD4M(U,P,T,X)** 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°C to 399.85 °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* <u>and</u> p = -1000 or the given value for *p* <u>and</u> t = -1000 and in both cases the value for *x* between 0 and 1 must be entered.

If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program considers *p* and *t* to be appropriate to represent the vapor pressure curve.

Wet steam region: Temperature ranges from $t = 26.85°C$ to $t_c = 379.05°C$
Pressure ranges from $p_s(26.85°C) = 0.00001093377$ 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: (x = -1)
p > 300 bar or p < 0.00001 bar or
t > 399.85 °C or t < 26.85°C

Wet steam region:
at p = -1000 and $t > t_c$ = 379.05 °C or t < 26.85 °C
at t = -1000 and $p > p_c$ = 8.7747391 bar
or $p < p_s$(26.85°C) = 0.00001093377 bar or
at $p > p_c$ = 8.7747391 bar or $p < p_s$(26.85°C) = 0.00001093377 bar and
$t > t_c$ = 379.05 °C or t < 26.85°C

References: [1]

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

Function Name:	**v_ptx_MD4M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION VPTXMD4M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_VPTXMD4M(V,P,T,X)** REAL*8 V,P,T,X

Input Values:

P - Pressure p in bar

T - Temperature t in °C

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

Result

VPTXMD4M, **V** or **v_ptx_MD4M** - Specific volume v in m^3/kg

Range of validity

Temperature range: from t = 26.85°C to 399.85 °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 <u>and</u> p = -1000 or the given value for p <u>and</u> t = -1000 and in both cases the value for x between 0 and 1 must be entered.

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

Wet steam region: Temperature ranges from $t = 26.85°C$ to $t_c = 379.05°C$
Pressure ranges from $p_s(26.85°C) = 0.00001093377$ 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: (x = -1)
p > 300 bar or p < 0.00001 bar or
t > 399.85 °C or t < 26.85°C

Wet steam region:
at p = -1000 and $t > t_c$ = 379.05 °C or t < 26.85 °C
at t = -1000 and $p > p_c$ = 8.7747391 bar
or $p < p_s$(26.85°C) = 0.00001093377 bar or
at $p > p_c$ = 8.7747391 bar or $p < p_s$(26.85°C) = 0.00001093377 bar and
$t > t_c$ = 379.05 °C or t < 26.85°C

References: [1]

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

Function Name:	**w_ptx_MD4M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION WPTXMD4M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_WPTXMD4M(W,P,T,X)** REAL*8 W,P,T,X

Input Values:

P - Pressure *p* in bar

T - Temperature *t* in °C

X - Vapor fraction *x* (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°C to 399.85 °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* <u>and</u> p = -1000, or the given value for *p* <u>and</u> t = -1000, plus the value for *x* (x = 0 or x = 1). If *p* <u>and</u> *t* <u>and</u> *x* are entered as given values, the program will consider *p* and *t* to be appropriate to represent the vapor pressure curve.

Saturated liquid and	Temperature ranges from $t = 26.85°C$ to $t_c = 379.05°C$
saturated vapor line:	Pressure ranges from $p_s(26.85°C) = 0.00001093377$ 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: (x = -1)	p > 300 bar or p < 0.00001 bar or t > 399.85 °C or t < 26.85°C
Boiling or dew curve:	at p = -1000 and $t > t_c$ = 379.05 °C or t < 26.85 °C at t = -1000 and $p > p_c$ = 8.7747391 bar or $p < p_s$(26.85°C) = 0.00001093377 bar or at $p > p_c$ = 8.7747391 bar or $p < p_s$(26.85°C) = 0.00001093377 bar and $t > t_c$ = 379.05 °C or t < 26.85°C

References: [1]

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

Function Name:	**x_ph_MD4M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION XPHMD4M(P,H)** REAL*8 P,H
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_XPHMD4M(X,P,H)** 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 $t = 26.85°C$ to $t_c = 380.05$ °C

Pressure range: from $p_s(26.85°C) = 0.00001093377$ 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 $p_s(26.85°C) = 0.00001093377$ 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: for call from Fortran	**REAL*8 FUNCTION XPSMD4M(P,S)** REAL*8 P,S
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_XPSMD4M(X,P,S)** 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 $t = 26.85°C$ to $t_c = 380.05$ °C

Pressure range: from $p_s(26.85°C) = 0.00001093377$ 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 $p_s(26.85°C) = 0.00001093377$ 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 $p < p_s(26.85°C) = 0.00001093377$ bar

References: [1]

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

Function Name:	**Z_ptx_MD4M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION ZPTXMD4M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_ZPTXMD4M(Z,P,T,X)** 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°C to 399.85 °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 <u>and</u> p = -1000, or the given value for p <u>and</u> t = -1000, plus the value for x between 0 and 1. When calculating wet steam and p <u>and</u> t <u>and</u> x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve.

Boiling and dew curve: Temperature ranges from $t = 26.85°C$ to $t_c = 380.05°C$

Pressure ranges from $p_s(26.85°C) = 0.00001093377$ 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: (x = -1)
p > 300 bar or p < 0.00001 bar or
t > 399.85 °C or t < 26.85°C

Boiling or dew curve:
at p = -1000 and $t > t_c$ = 380.05 °C or t < 26.85 °C
at t = -1000 and $p > p_c$ = 8.7747391 bar
or $p < p_s(26.85°C)$ = 0.00001093377 bar or
at $p > p_c$ = 8.7747391 bar or $p < p_s(26.85°C)$ = 0.00001093377 bar and
$t > t_c$ = 380.05 °C or t < 26.85°C

References: [1]

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Department of Technical Thermodynamics
www.thermodynamics-zittau.de

4. 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)

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:

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

and of the ideal gases:

SO_2, CO, Ne (Scientific Formulation of Bücker et al.)

Consideration of:

Dissociation from VDI 4670 and 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 the VDI 4670
- Poynting effect from ASHRAE RP-1485

Carbon Dioxide including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1994)

Seawater

Library LibSeaWa

IAPWS Formulation 2008 of Feistel and IAPWS-IF97

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

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

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Dry Air including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Nitrogen

Library LibN2

Formulation of Span et al. (2000)

Hydrogen

Library LibH2

Formulation of Leachman et al. (2007)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth (1995)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bücker et al. (2003)

n-Butane

Library LibButane_n

Formulation of Bücker et al. (2003)

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 Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

$C_2H_6O_2$	Ethylene glycol
$C_3H_8O_2$	Propylene glycol
C_2H_5OH	Ethyl alcohol
CH_3OH	Methyl alcohol
$C_3H_8O_3$	Glycerol
K_2CO_3	Potassium carbonate
$CaCl_2$	Calcium chloride
$MgCl_2$	Magnesium chloride
NaCl	Sodium chloride
$C_2H_3KO_2$	Potassium acetate

Formulation of the International Institute of Refrigeration (1997)

Siloxanes as ORC Working Fluids

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

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Propane

Library LibPropane

Formulation of Lemmon et al. (2007)

Methanol

Library LibCH3OH

Formulation of de Reuck and Craven (1993)

Ethanol

Library LibC2H5OH

Formulation of Schroeder et al. (2012)

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_5H_{14} **Library LibC5H14**

Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

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

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

Hydrogen sulfide H_2S **Library LibH2S**

Dinitrogen monooxide N_2O **Library LibN2O**

Sulfur dioxide SO_2 **Library LibSO2**

Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

For more information please contact:

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Phone: +49-3583-61-1846
Fax.: +49-3583-61-1846

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

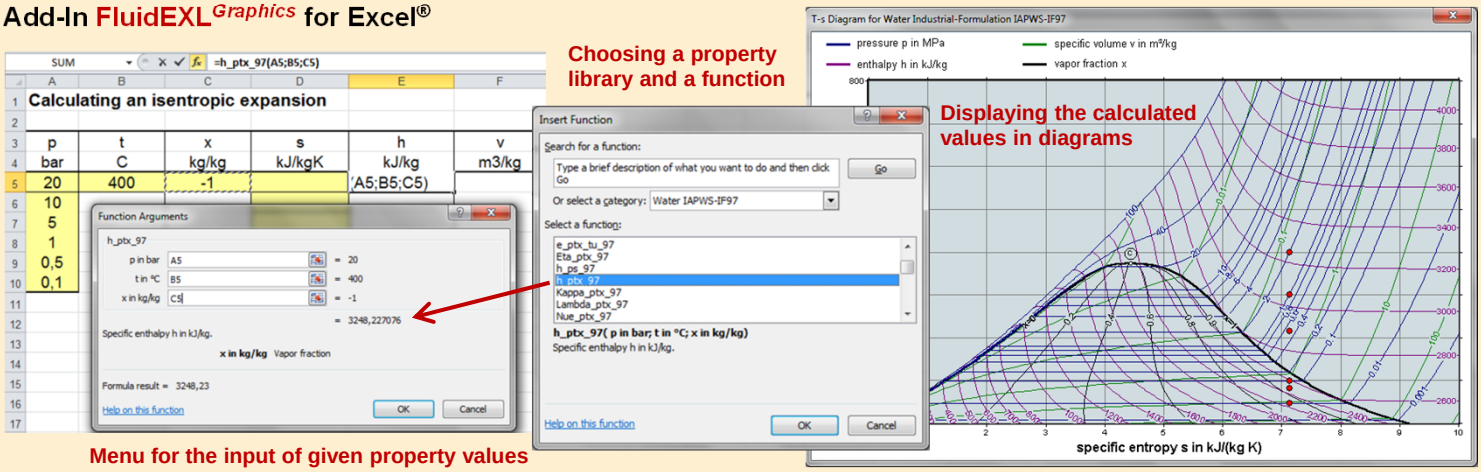
[a] Not all of these property functions are available in all property libraries.

www.thermodynamic-property-libraries.com

ZITTAU/GOERLITZ UNIVERSITY OF APPLIED SCIENCES
Department of Technical Thermodynamics
www.thermodynamics-zittau.de

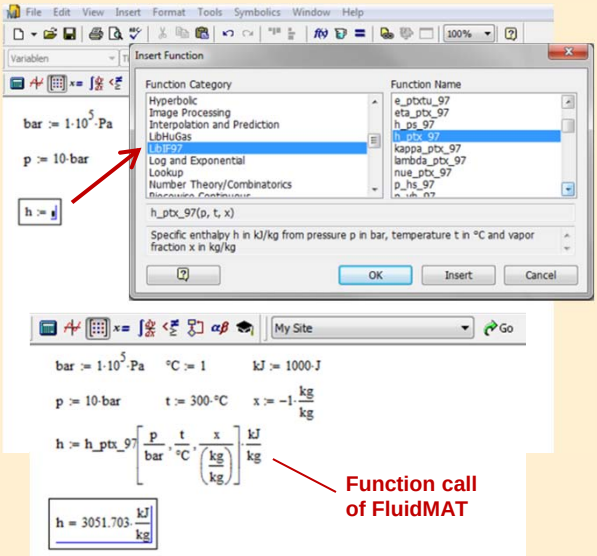
Property Software for Calculating Heat Cycles, Boilers, Turbines, and Refrigerators

Add-In FluidEXL*Graphics* for Excel®



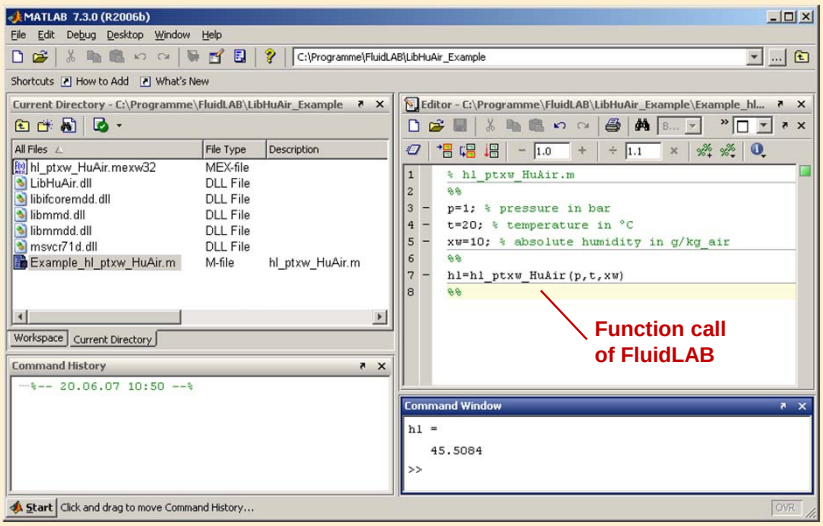
Add-In FluidMAT for Mathcad®

The property libraries can be used in Mathcad®.



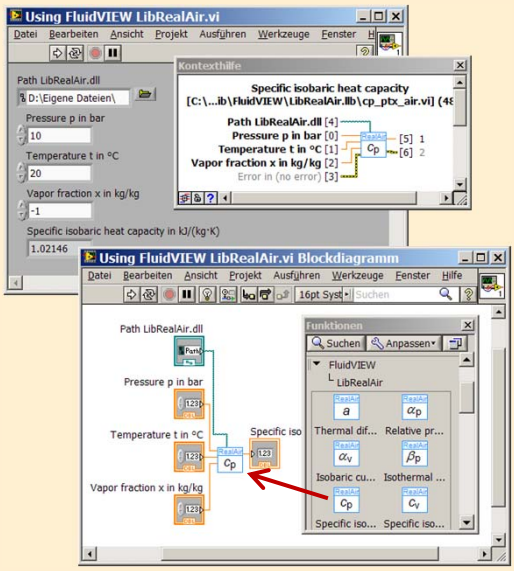
Add-In FluidLAB for MATLAB®

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



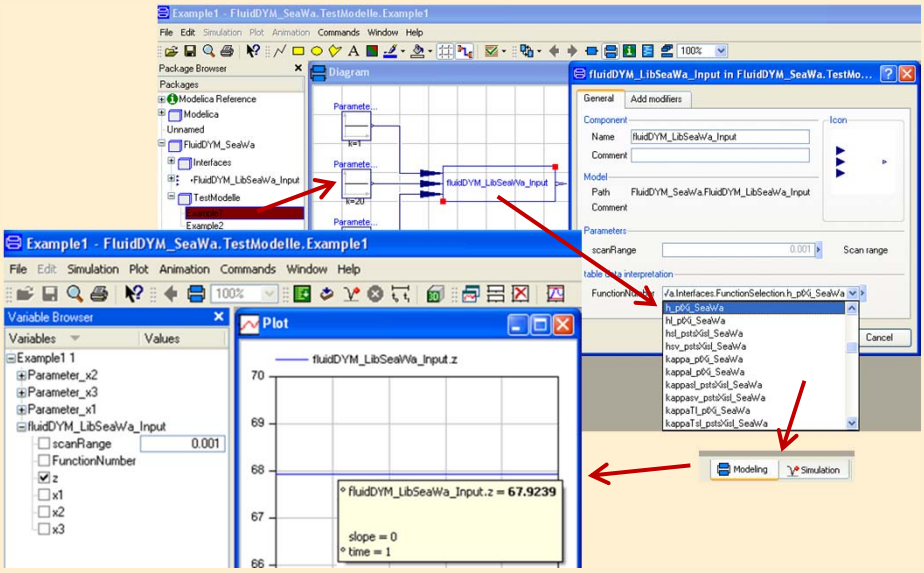
Add-On FluidVIEW for LabVIEW®

The property functions can be calculated in LabVIEW®.

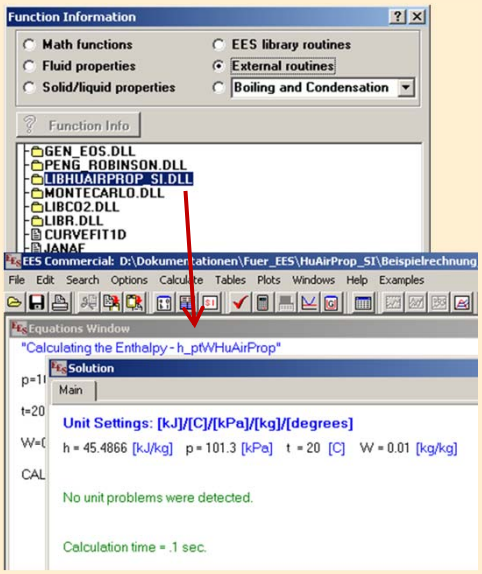


Add-In FluidDYM for DYMOLA® (Modelica) and SimulationX®

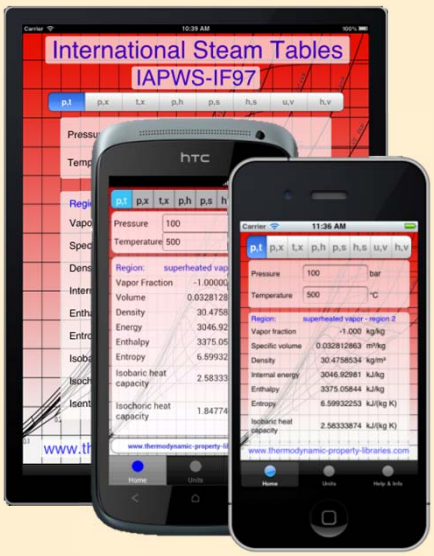
The property functions can be called in DYMOLA® and SimulationX®



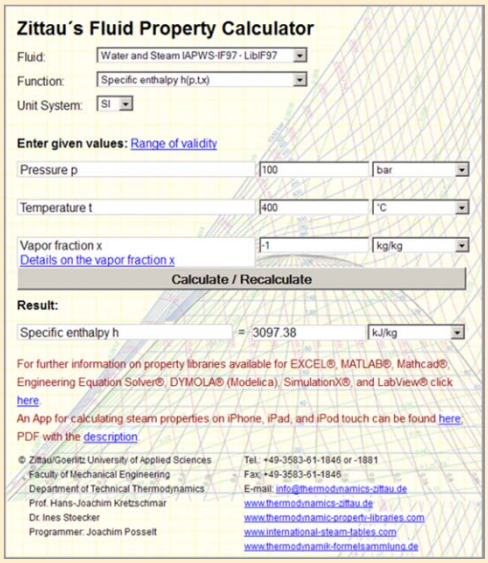
Add-In FluidEES for Engineering Equation Solver®



App International Steam Tables for iPhone, iPad, iPod touch, Android smart phones and tablets



Online Property Calculator at www.thermodynamics-zittau.de



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 83, TI 84, TI 89 | TI Voyage 200 | TI 92

For more information please contact:

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Phone: +49-3583-61-1846
Fax.: +49-3583-61-1846

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

www.thermodynamic-property-libraries.com

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: 10/2011

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)
- FluidVIEW for LabVIEW®:

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
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RWTH Aachen University	07/2011, 08/2011
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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
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University of Duisburg	03/2011, 06/2011
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BASF, Ludwigshafen	02/2011
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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

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KRONES, Neutraubling	10/2010

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University of Rostock, Chair in Technical Thermodynamics	11/2007, 12/2007

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Enertech Energie und Technik, Radebeul	12/2006

2005

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J.H.K Plant Engineering and Service, Bremerhaven	01/2005
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eta Energieberatung, Pfaffenhofen	02/2005
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STORA ENSO Sachsen, Eilenburg	12/2005
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2004

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MAN B&W Diesel A/S, Copenhagen, Denmark	02/2004
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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 (general EBSILON program license)	06/2002
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 (company licenses and distribution)	08/2002
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 (general license and training test benches)	12/2002
VEAG, Berlin (group license)	12/2002

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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 (company licenses and distribution)	04/2001
Muenstermann GmbH, Telgte-Westbevern	05/2001
SaarEnergie, Saarbruecken	05/2001
Siemens, Karlsruhe (general license for the WinIS information system)	08/2001
Neusiedler AG, Ulmerfeld, Austria	09/2001
h s energieanlagen, 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

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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

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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

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