



Faculty of
MECHANICAL ENGINEERING

Department of
TECHNICAL THERMODYNAMICS

**Property Library for
Hexamethyldisiloxane (MM)
 $\text{C}_6\text{H}_{18}\text{OSi}_2$**

**FluidDYM
LibMM
for DYMOLA[®]**

Prof. Hans-Joachim Kretzschmar
Dr. Ines Stoecker
M. Kunick
M. Nimtz

Property Software for Hexamethyldisiloxane



FluidDYM for DYMOLA®

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© Zittau/Goerlitz University of Applied Sciences, Germany
Faculty of Mechanical Engineering
Department of Technical Thermodynamics
Prof. Hans-Joachim Kretzschmar
Dr. Ines Stoecker
Phone: +49-3583-61-1846 or -1881
Fax: +49-3583-61-1846
E-mail: hj.kretzschmar@hs-zigr.de
Internet: www.thermodynamics-zittau.de

0 Package Contents

Zip- file "CD_FluidDYM_LibMM_Eng.zip" including the following files:

FluidDYM_LibMM_Setup.exe	- Installation Program for the FluidDYM Add-In for use in DYMOLA®
LibMM.dll	- Dynamic Link Library for Hexamethyldisiloxane MM for use in DYMOLA®
FluidDYM_LibMM_Docu_Eng.pdf	User's Guide
Folder "Users_Guide"	Includes the complete User's Guide

1 Property Functions

1.1 Calculation Programs

“MM” means Hexamethyldisiloxane ($\text{C}_6\text{H}_{18}\text{OSi}_2$)

Functional Dependence	Function Name	Call from Fortran program	Call in DLL LibMM as parameter	Property or Function	Unit of the result
$c_p = f(p, t, x)$	cp_ptx_MM	CPPTXMM(P,T,X)	C_CPPTXMM(CP,P,T,X)	Specific isobaric heat capacity	kJ/(kg K)
$c_v = f(p, t, x)$	cv_ptx_MM	CVPTXMM(P,T,X)	C_CVPTXMM(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_MM	DPDVTMM(P,T,X)	C_DPDVTMM(DPDT,P,T,X)	Derivative of pressure with respect to temperature (at constant spec. volume)	kPa/K
$\left(\frac{\partial p}{\partial v}\right)_T = f(p, t, x)$	dpdvt_ptx_MM	DPDVTMM(P,T,X)	C_DPDVTMM(DPDV,P,T,X)	Derivative of pressure with respect to specific volume (at constant temperature)	kPa/(m ³ /kg)
$h = f(p, t, x)$	h_ptx_MM	HPTXMM(P,T,X)	C_HPTXMM(H,P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p, t, x)$	kappa_ptx_MM	KAPPAPTMM(P,T,X)	C_KAPPAPTMM(KAPPA,P,T,X)	Isentropic exponent	-
$p_s = f(t)$	ps_t_MM	PSTMM(T)	C_PSTMM(PS,T)	Vapor pressure from temperature	bar
$\rho = f(p, t, x)$	rho_ptx_MM	RHOPTXMM(P,T,X)	C_RHOPTXMM(RHO,P,T,X)	Density	kg/m ³
$s = f(p, t, x)$	s_ptx_MM	SPTXMM(P,T,X)	C_SPTXMM(S,P,T,X)	Specific entropy	kJ/(kg K)
$t = f(p, h)$	t_ph_MM	TPHMM(P,H)	C_TPHMM(T,P,H)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p, s)$	t_ps_MM	TPSMM(P,S)	C_TPSMM(T,P,S)	Backward function: Temperature from pressure and entropy	°C
$t_s = f(p)$	ts_p_MM	TSPMM(P)	C_TSPMM(TS,P)	Boiling temperature from pressure	°C
$u = f(p, t, x)$	u_ptx_MM	UPTXMM(P,T,X)	C_UPTXMM(U,P,T,X)	Specific internal energy	kJ/kg
$v = f(p, t, x)$	v_ptx_MM	VPTXMM(P,T,X)	C_VPTXMM(V,P,T,X)	Specific volume	m ³ /kg
$w = f(p, t, x)$	w_ptx_MM	WPTXMM(P,T,X)	C_WPTXMM(W,P,T,X)	Isentropic speed of sound	m/s
$x = f(p, h)$	x_ph_MM	XPHMM(P,H)	C_XPHMM(X,P,H)	Backward function: Vapor fraction from pressure and enthalpy	kg/kg
$x = f(p, s)$	x_ps_MM	XPSMM(P,S)	C_XPSMM(X,P,S)	Backward function: Vapor fraction from pressure and entropy	kg/kg
$Z = f(p, t, x)$	Z_ptx_MM	ZPTXMM(P,T,X)	C_ZPTXMM(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 $t = -0.15^\circ\text{C}$ 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 $t_B = 100.251^\circ\text{C}$ on the boiling curve ($x = 0$; $p_s = p_N = 1.01325$ bar)

Details on the vapor fraction x

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

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

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

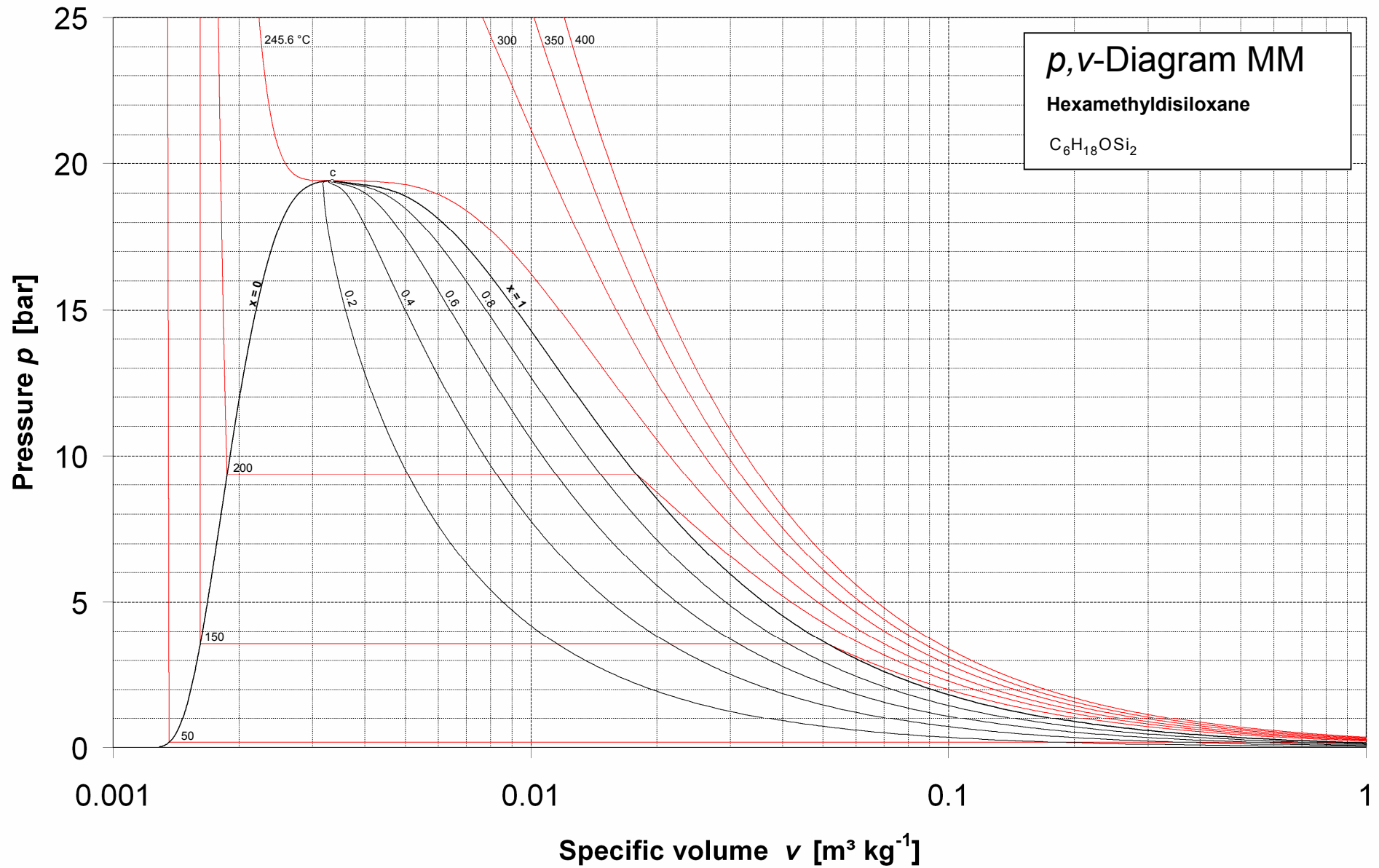
If the state point to be calculated is located in the two phase region, it is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When calculating wet steam and p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000 .

Wet steam region: Temperature range from $t = -0.15^\circ\text{C}$ to $t_c = 245.6^\circ\text{C}$
 Pressure range from $p_s (-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

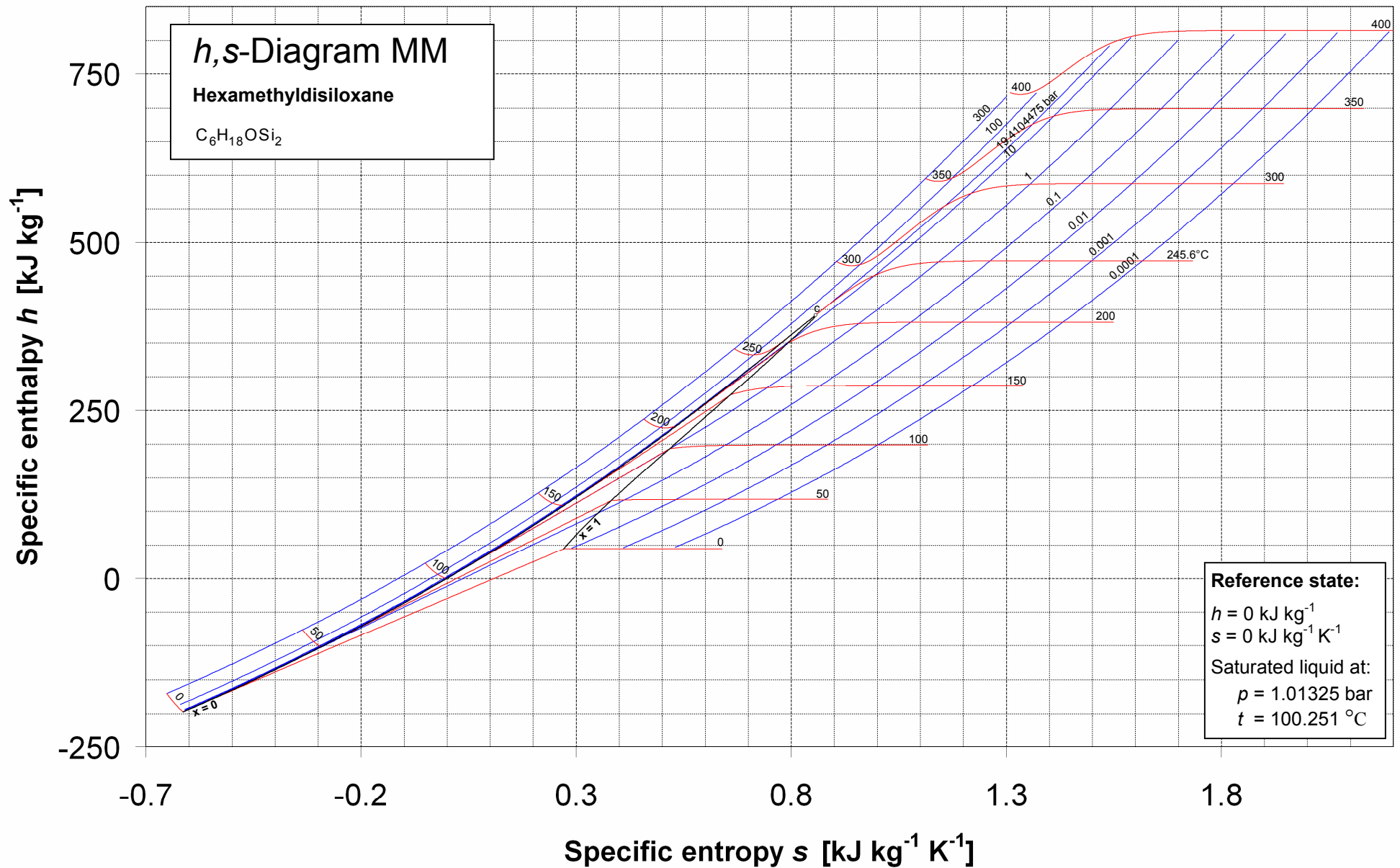
Note.

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

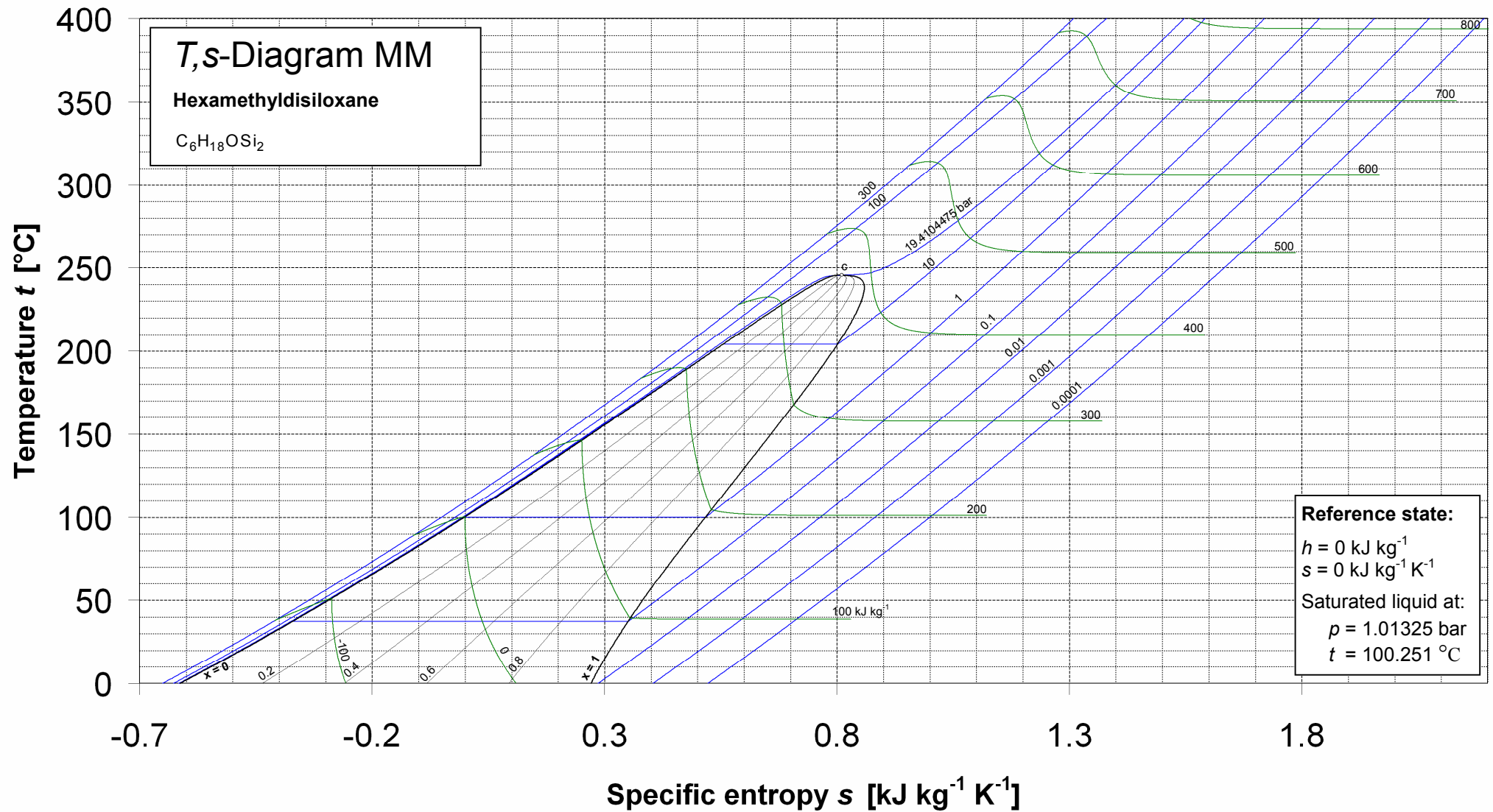
1.2 p,v -Diagram



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 Hexamethyldisiloxane from the LibMM 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_LibMM_Eng.zip", you will see the folder

CD_FluidDYM_LibMM_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_LibMM_Docu_Eng.pdf

FluidDYM_LibMM_Setup.exe.

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

FluidDYM_LibMM_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\LibMM" (see Figure 2.1).

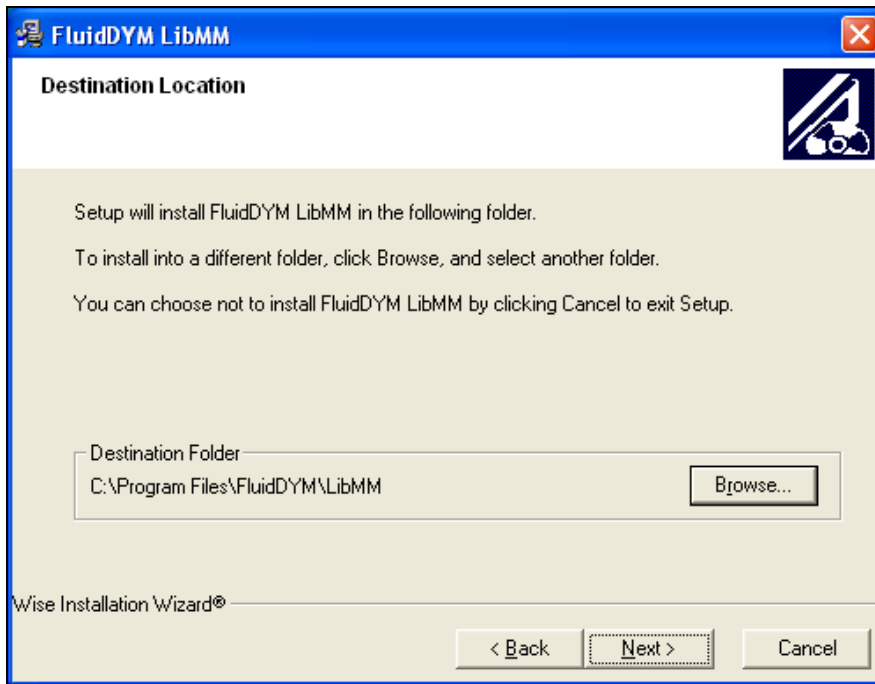


Figure 2.1: Dialog window "Destination Location"

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\LibMM":

- Dynamic link library "LibMM.dll".
- Link up Dynamic link library "LibMM_Dym.dll" and other necessary system DLL files.
- Library File "LibMM_DYM.lib"
- Header File "LibMM_DYM.h" and other necessary system DLL files.
- Modelica File "FluidDYM_LibMM.mo", includes the following property functions:

cp_ptx_MM	t_ph_MM
cv_ptx_MM	t_ps_MM
dpgtv_ptx_MM	ts_p_MM
dpgvt_ptx_MM	u_ptx_MM
h_ptx_MM	v_ptx_MM
kappa_ptx_MM	w_ptx_MM
ps_t_MM	x_ph_MM
rho_ptx_MM	x_ps_MM
s_ptx_MM	Z_ptx_MM

Now, you have to overwrite the file "LibMM.dll" in your LibMM directory with the file of the same name provided in your CD folder with FluidDYM.

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

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

Now, open your LibMM directory (the standard being

C:\Program Files\FluidDYM\LibMM)

and insert the file "LibMM.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 "LibMM.dll" successfully.

In the next step, copy the folder "Users_Guide" into your Dymola LibMM directory with the file of the same name provided in your CD folder of FluidDYM.

To do this, open the CD folder "CD_FluidDYM_LibMM_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 LibMM directory (the standard being:

C:\Program Files\FluidDYM\LibMM)

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 LibMM 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).

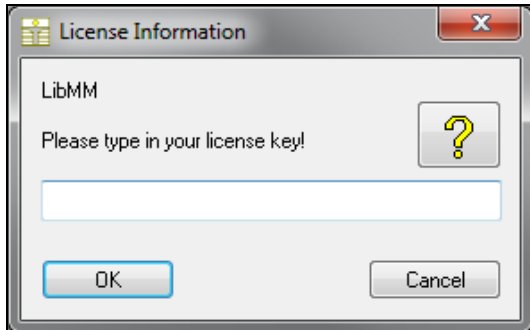


Figure 2.2: "License Information" window

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:

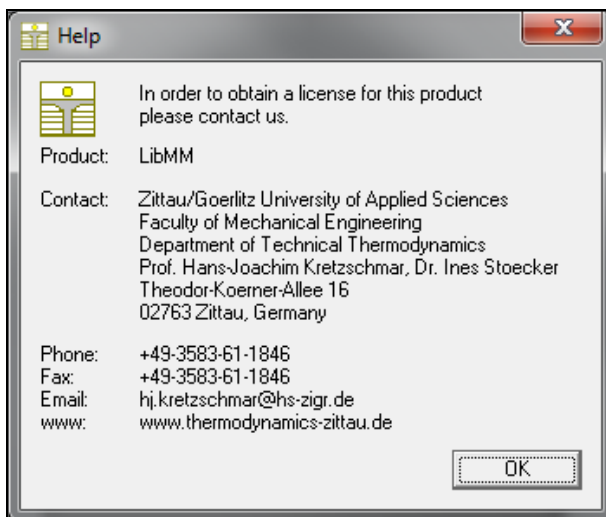


Figure 2.3: "Help" window

If you do not enter a valid license it is still possible to use DYMOLA[®] by clicking "Cancel". In this case, the LibMM 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_LibMM according to the description in section 2.3 of this User's Guide. Should you not wish to license the LibMM property library, you have to delete the files

LibMM.dll
 LibMM_DYM.dll
 LibMM_DYM.lib
 LibMM_DYM.h
 LibMM_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 Hexamethyldisiloxane

Now we will calculate, step by step, the specific enthalpy h of Hexamethyldisiloxane 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 "\LibMM"; the standard location is: "C:\Program Files\FluidDYM\LibMM"
- Create the folder "\LibMM_Example" by clicking on "File" in the Explorer menu, then "New" in the menu which appears, and then selecting "Folder". Name the new folder "\LibMM_Example".
- You will see the following window:

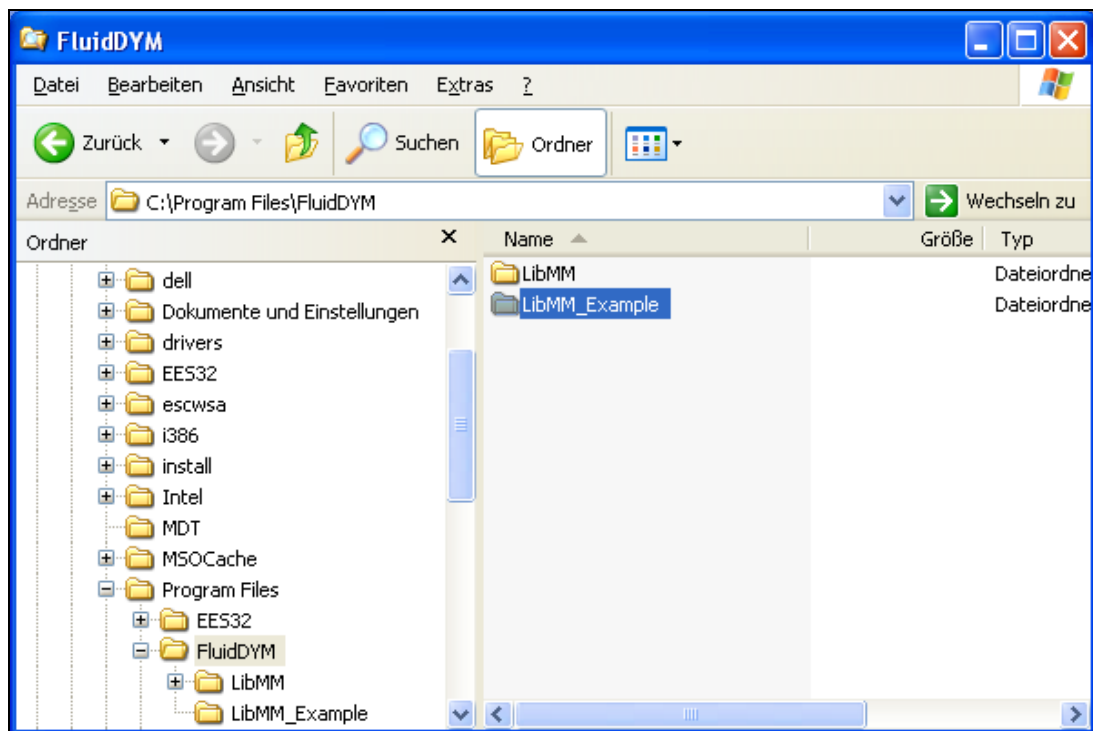


Figure 2.4: Highlighted *LibMM_Example* directory in FluidDYM

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

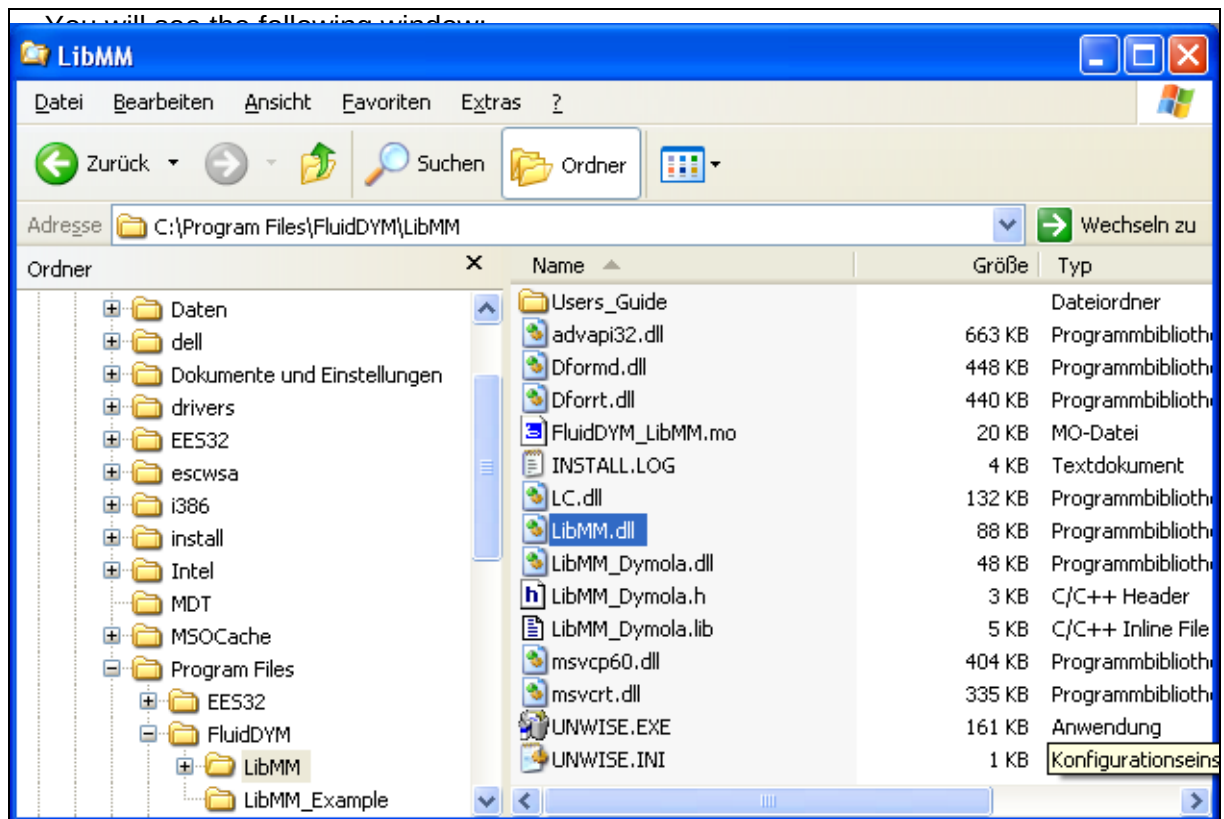


Figure 2.5: *LibMM* directory including installed files

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\LibMM_Example":

- "advapi32.dll"
 - "Dformd.dll"
 - "Dforrt.dll"
 - "FluidDYM_LibMM.mo"
 - "LC.dll"
 - "LibMM.dll"
 - "LibMM_Dymola.dll"
 - "LibMM_Dymola.h"
 - "LibMM_Dymola.lib"
 - "msvc60.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\LibMM_Example", click "Edit" and then "Paste".

- You will see the following window:

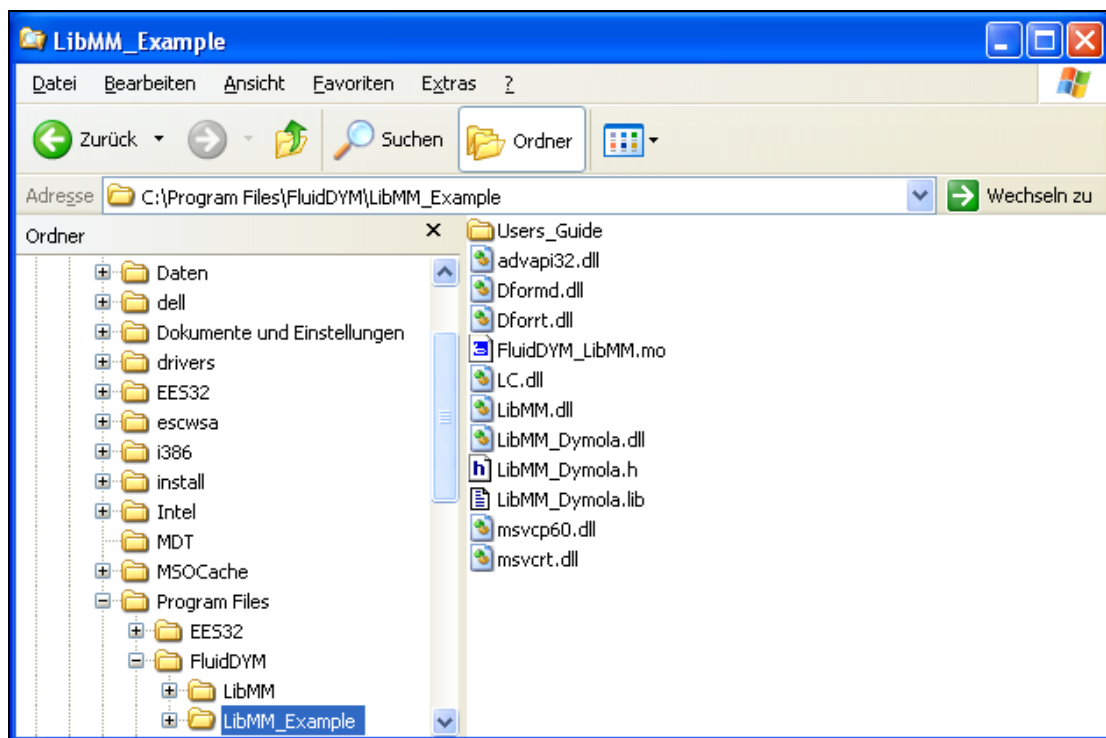


Figure 2.6: *LibMM_Example* directory including the newly-copied files

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

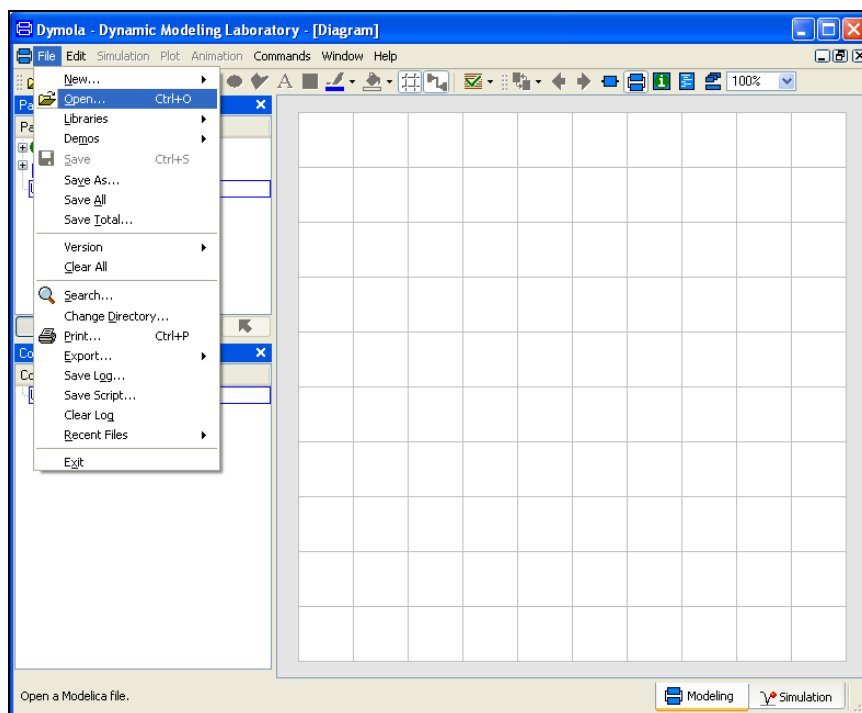


Figure 2.7: Selecting the menu entry "Open"

- Search and click on the directory "C:\Program Files\FluidDYM\LibMM_Example" in the pop-up menu.

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

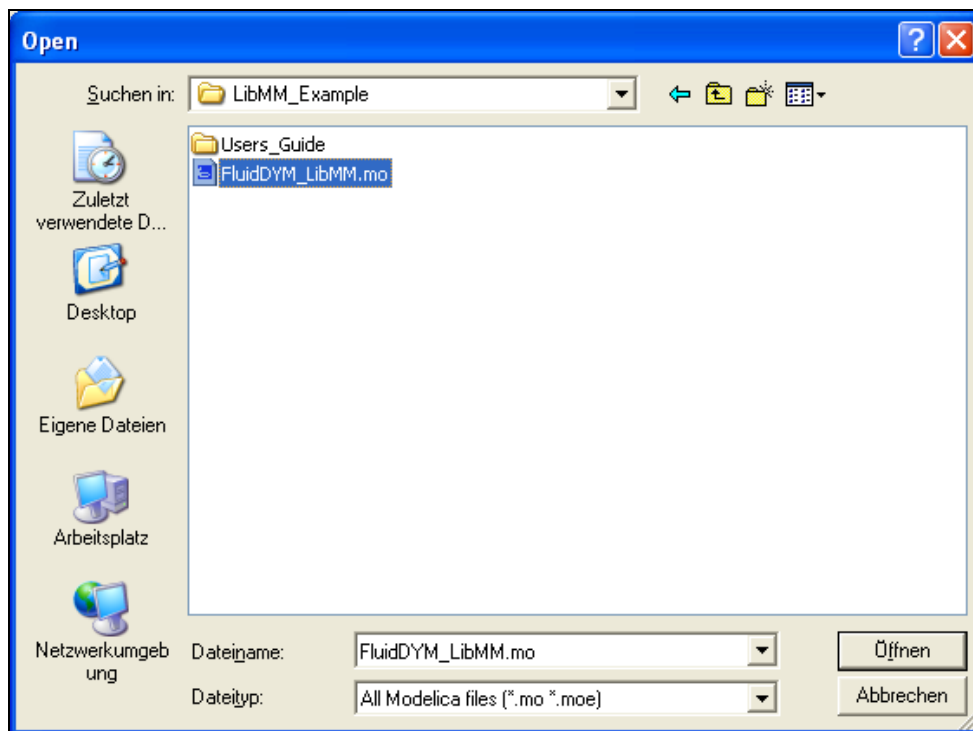


Figure 2.8: Selecting the *FluidDYM_LibMM.mo* file

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

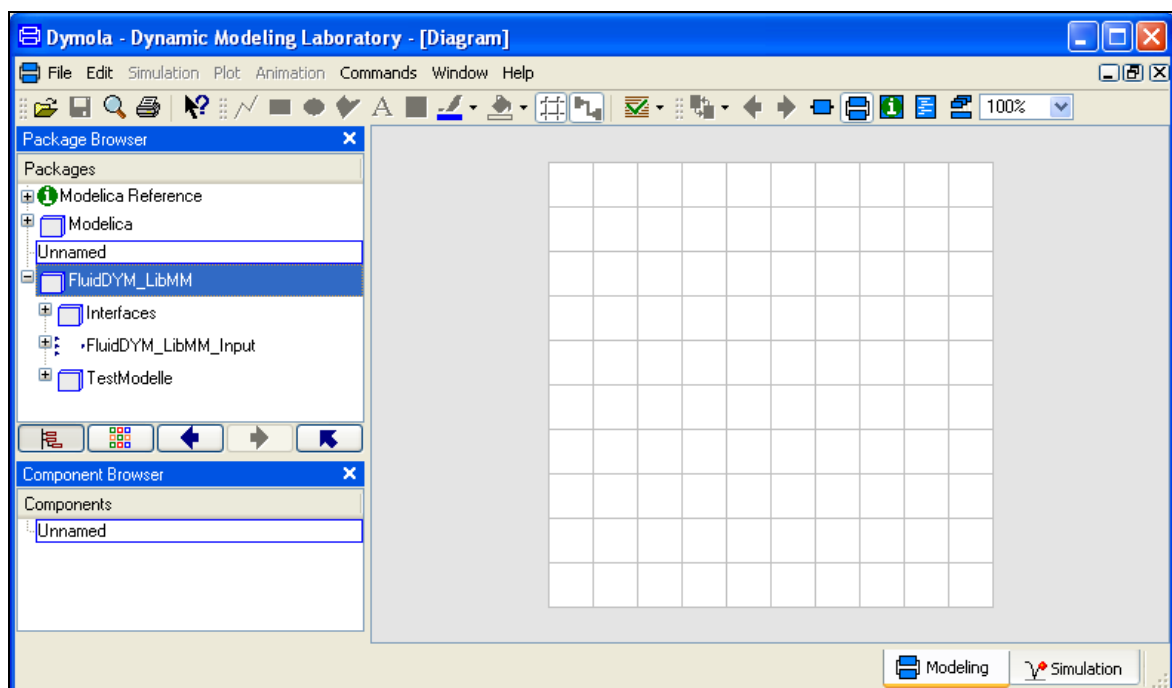


Figure 2.9: Dymola window after loading the *LibMM* library

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

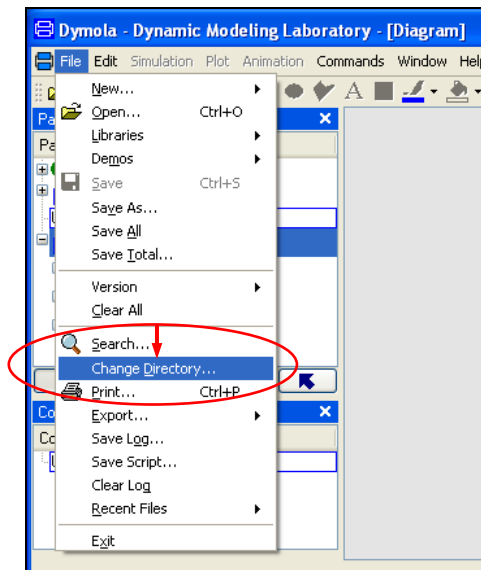


Figure 2.10: Selecting the menu entry "Change Directory..."

- Search and click on the directory "C:\Program Files\FluidDYM\LibMM_Example" in the pop-up menu (see Figure 2.11).

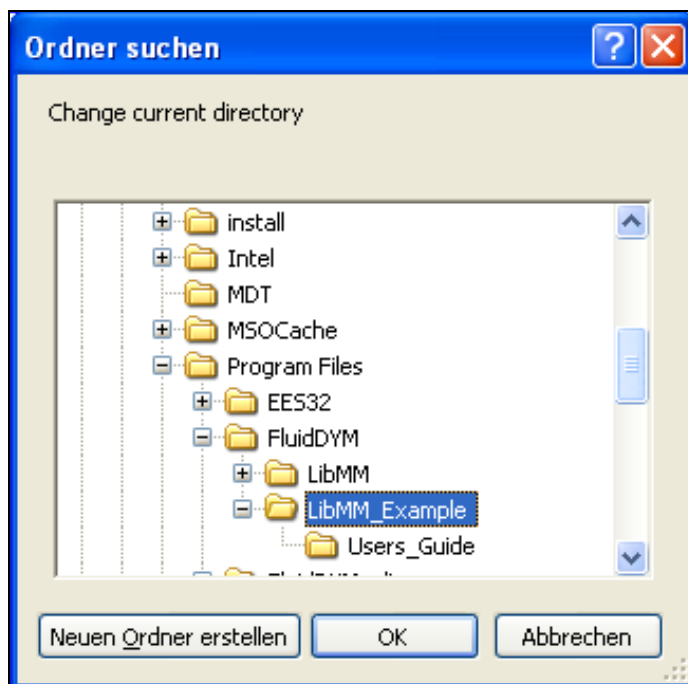


Figure 2.11: Selecting the *LibMM_Example* directory

- 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_MM" as follows for calculating $h = f(p, t, x)$.

- Click on the Dymola-Block "Testmodelle," which can be found in the FluidDYM_LibMM 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:

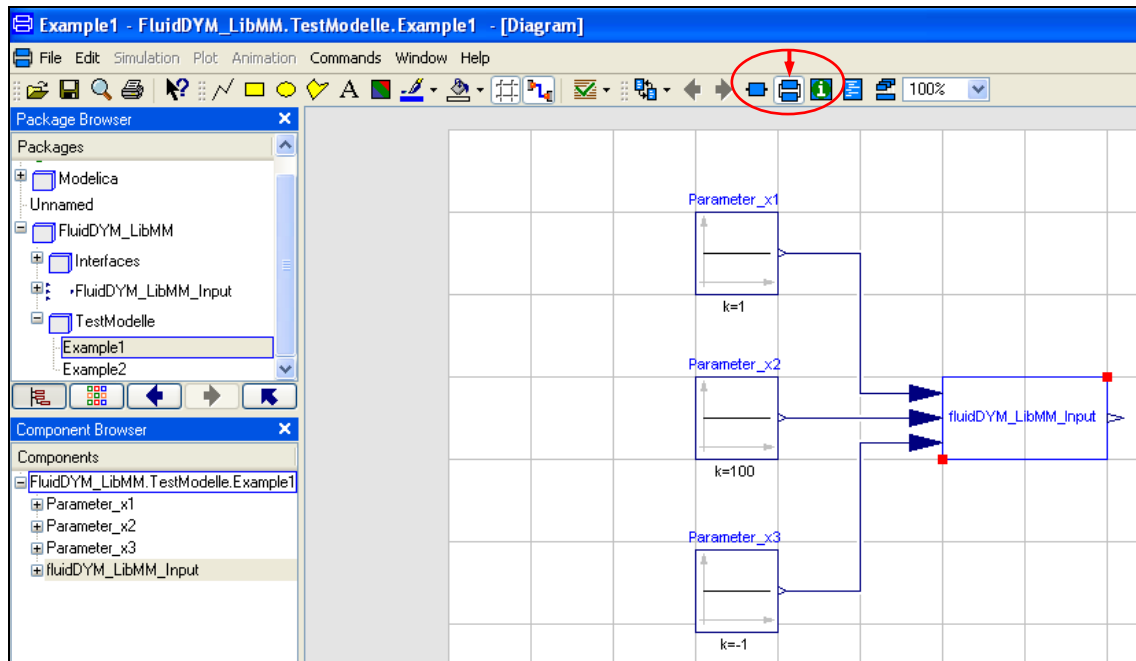


Figure 2.12: Dymola in Diagram Mode

- Now double-click on the "fluidDYM_LibMM_Input" block on the right hand side of the Dymola window.
- Search and click the "h_ptx_MM" function next to "Function Number" in the pop-up menu (see Figure 2.13).

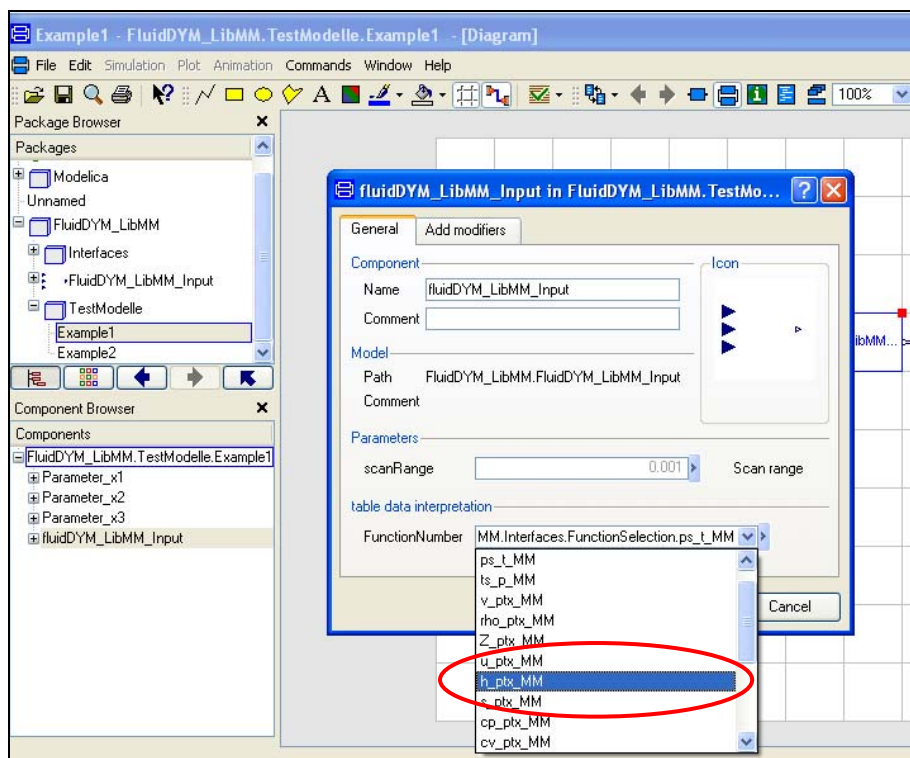


Figure 2.13: Choosing the function h_ptx_MM

- 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.

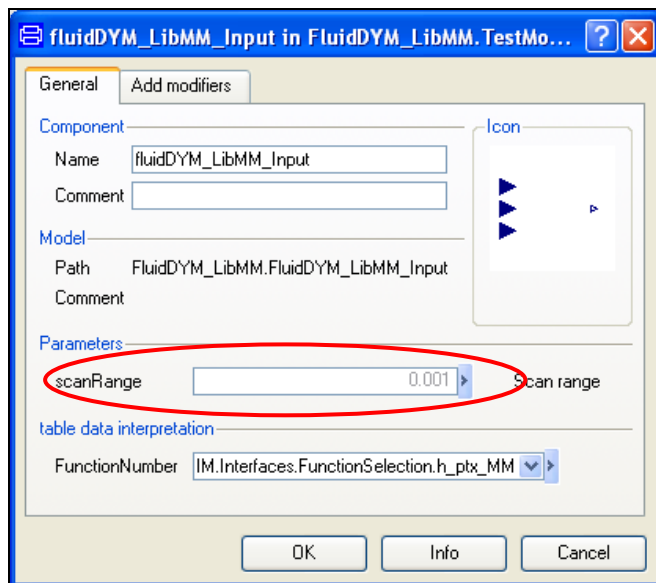


Figure 2.14: Setting the scan range

- Now we will configure the input parameters x_1 to x_3 , where x_1 represents the pressure p , x_2 represents the temperature t , and x_3 represents the vapor fraction x . When calculating a function with only two input parameters, the third input parameter x_3 will not be defined.
- First, double click on the "Parameter_x1" block which represents the first input parameter, here the pressure p in bar.

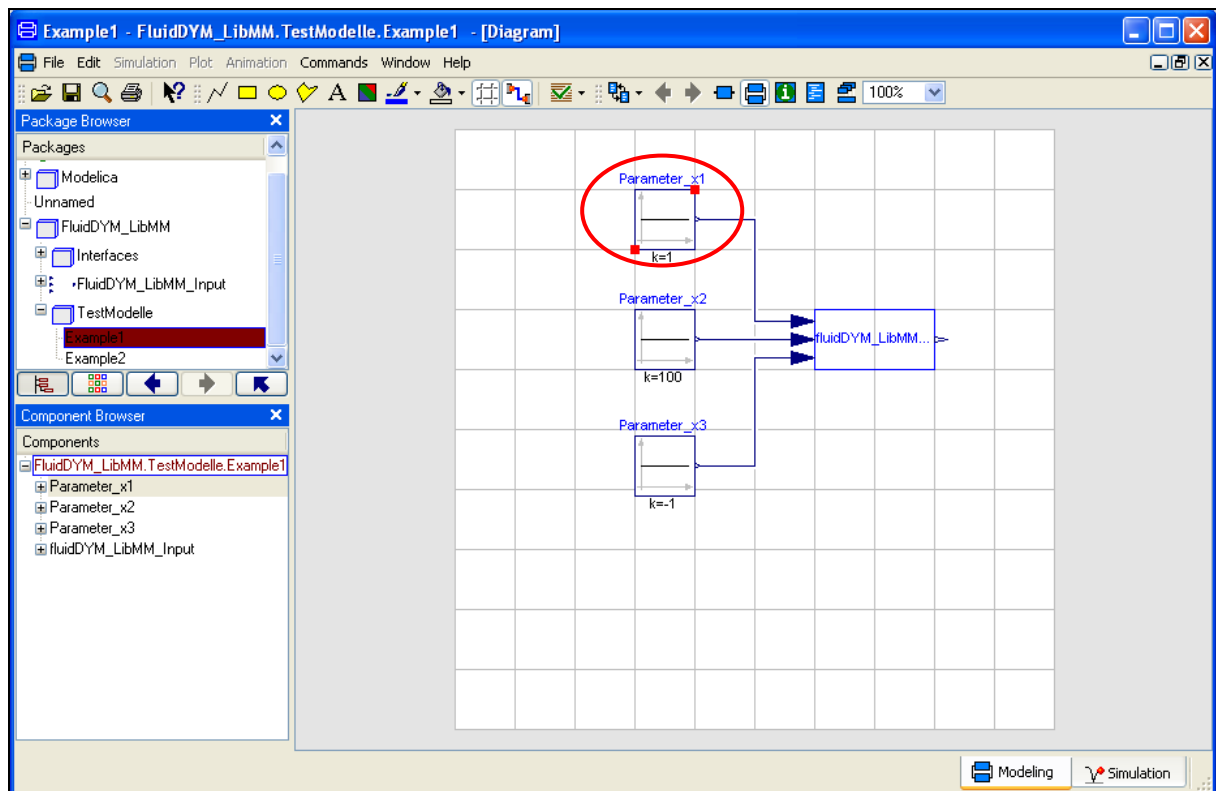


Figure 2.15: "Parameter_x1" block in Dymola

- 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).

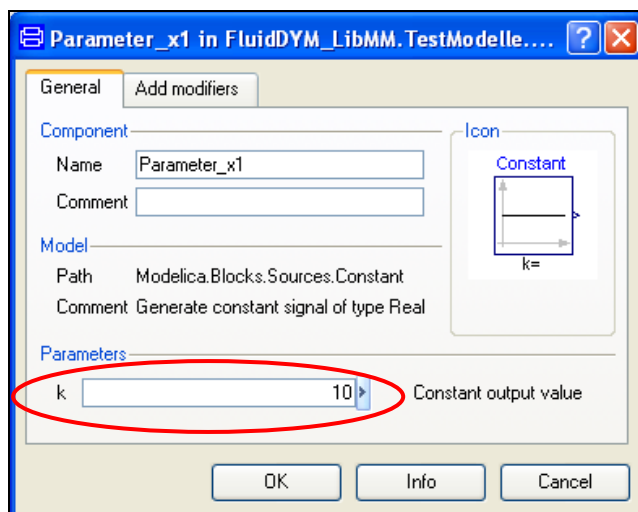


Figure 2.16: Entering the value for the pressure p

- 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).

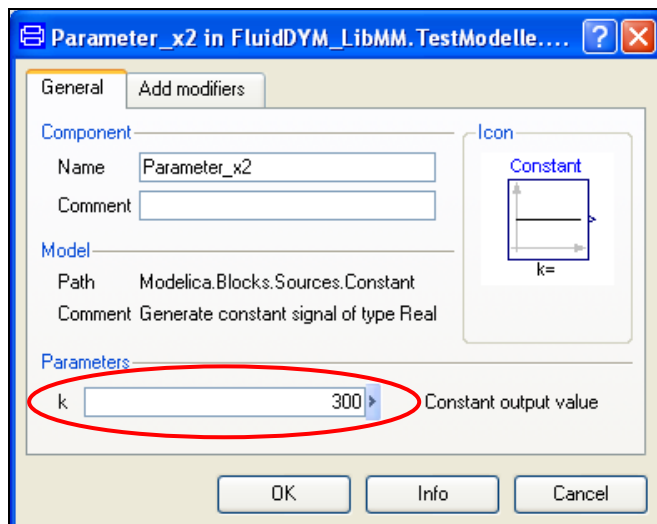


Figure 2.17: Entering the value for the temperature t

- Now, double click on the "Parameter_x3" block which represents the third input parameter, here the vapor fraction x in kg/kg.

Since the wet steam region is calculated automatically by the subprograms, 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), e. g., pressure p and temperature t are given, the value -1 must be entered into the x cell as a pro-forma value.

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

Here, it is adequate to enter either the value given for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x between 0 and 1.

However, if p and t and x are given when calculating wet steam, the program initially checks whether p and t meet the saturation-pressure curve. If this is not the case the enthalpy calculated later will result in -1000.

(MM Saturation pressure curve:

$$t = -0.15^{\circ}\text{C} \text{ to } t_c = 245.6^{\circ}\text{C}$$

$$p_s(-0.15^{\circ}\text{C}) = 0.01316986 \text{ bar to } p_c = 19.41004475 \text{ bar})$$

- 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).

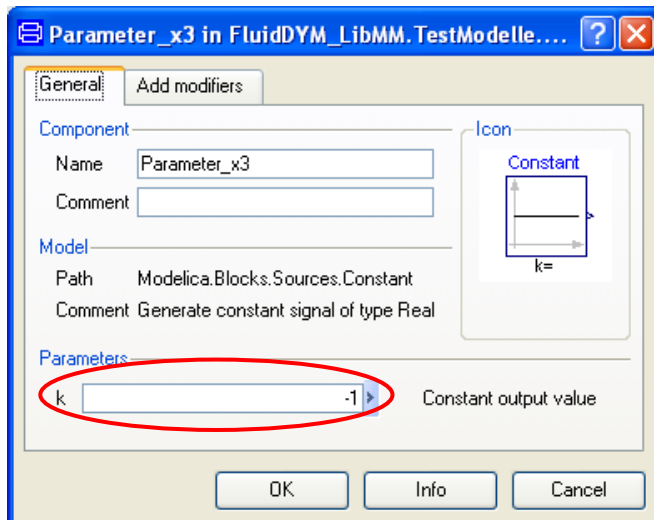
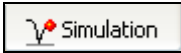


Figure 2.18: Entering the value for the vapor fraction x

All parameters have now been defined.

- Click on the  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.

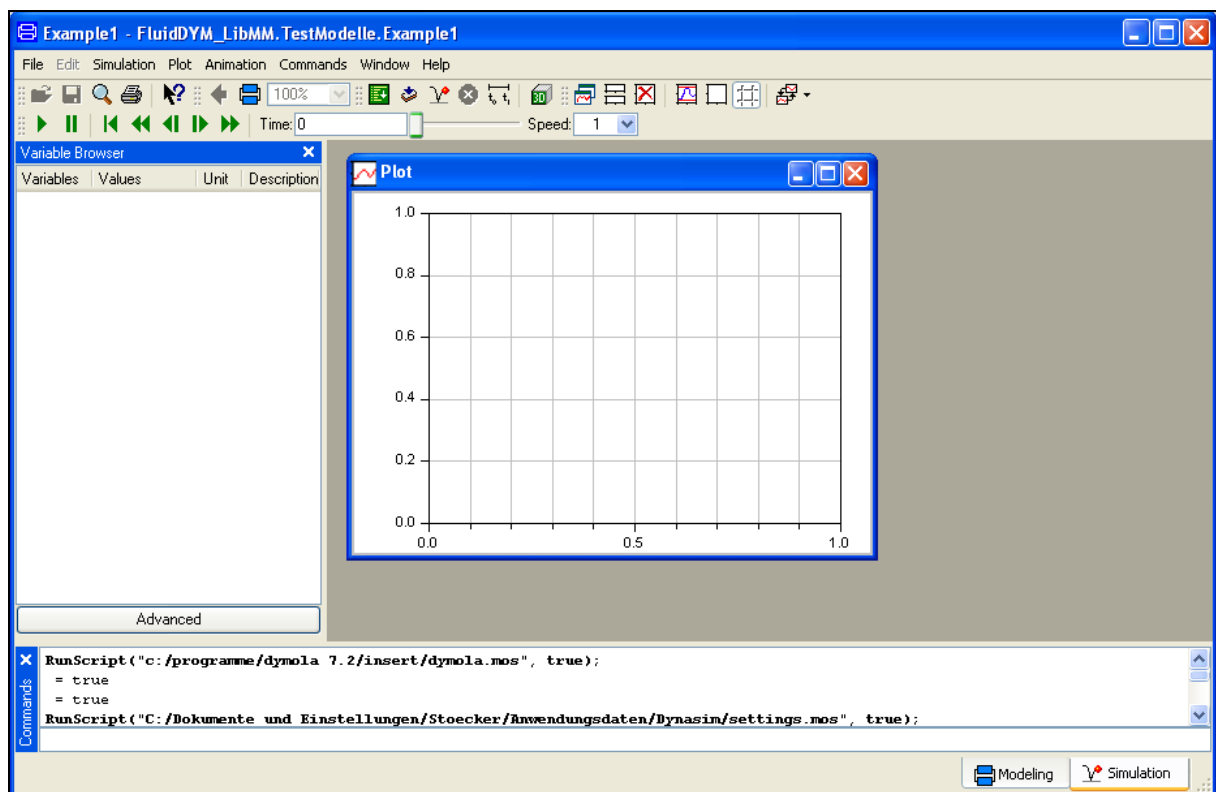


Figure 2.19: "Simulation Mode" window

- 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):

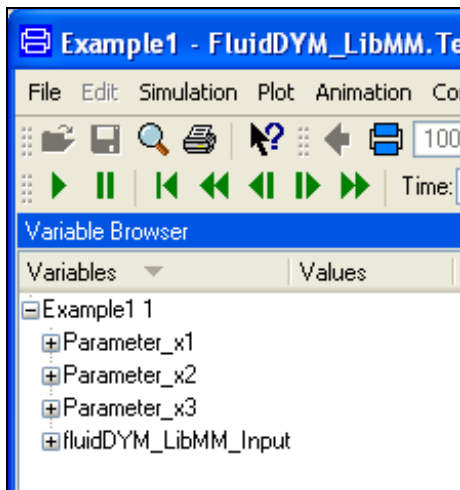


Figure 2.20: "Variable Browser" with new entries

- By clicking on the "New Plot Window" button , a new diagram window will be opened.
- Click on "fluidDYM_LibMM_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).

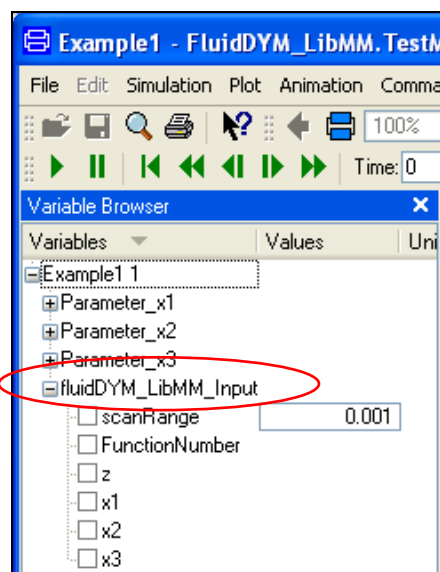


Figure 2.21: Parameters of *fluidDYM_LibMM_Input*

- 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).

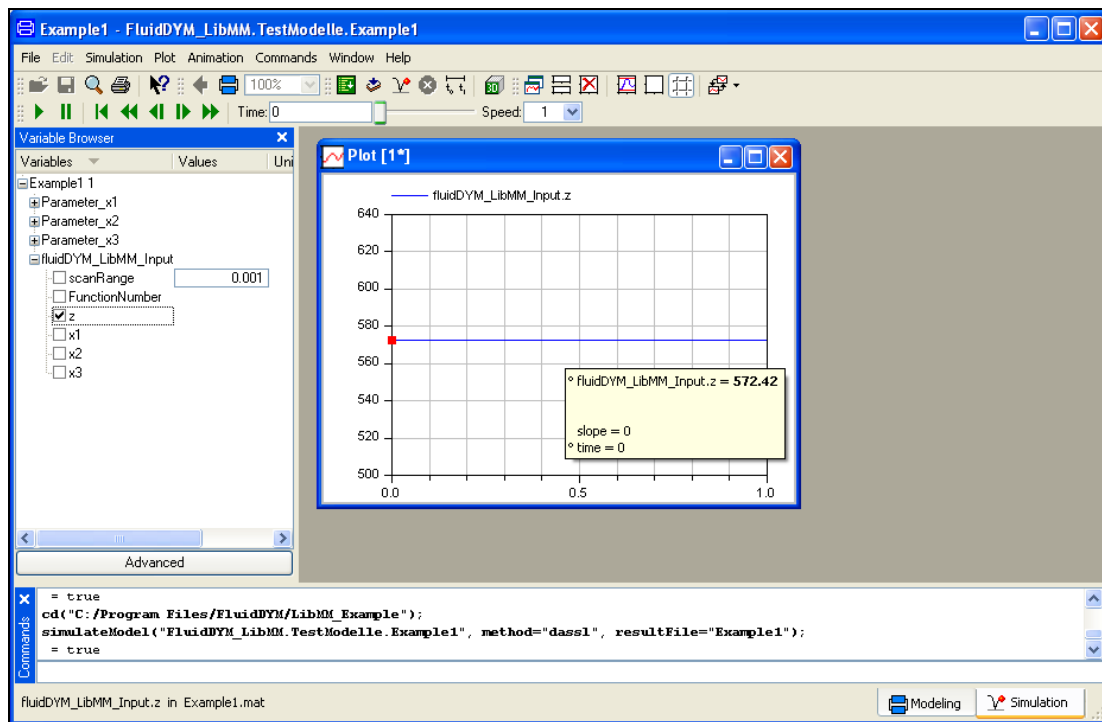


Figure 2.22: "DiagramWindow" showing the result

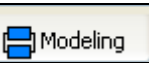
The result for h appears in the "DiagramWindow"

⇒ The result in our sample calculation here is: " $h = 572.42$ ". 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_LibMM" Block at the left and then click on "Users_Guide" (see Figure 2.23).

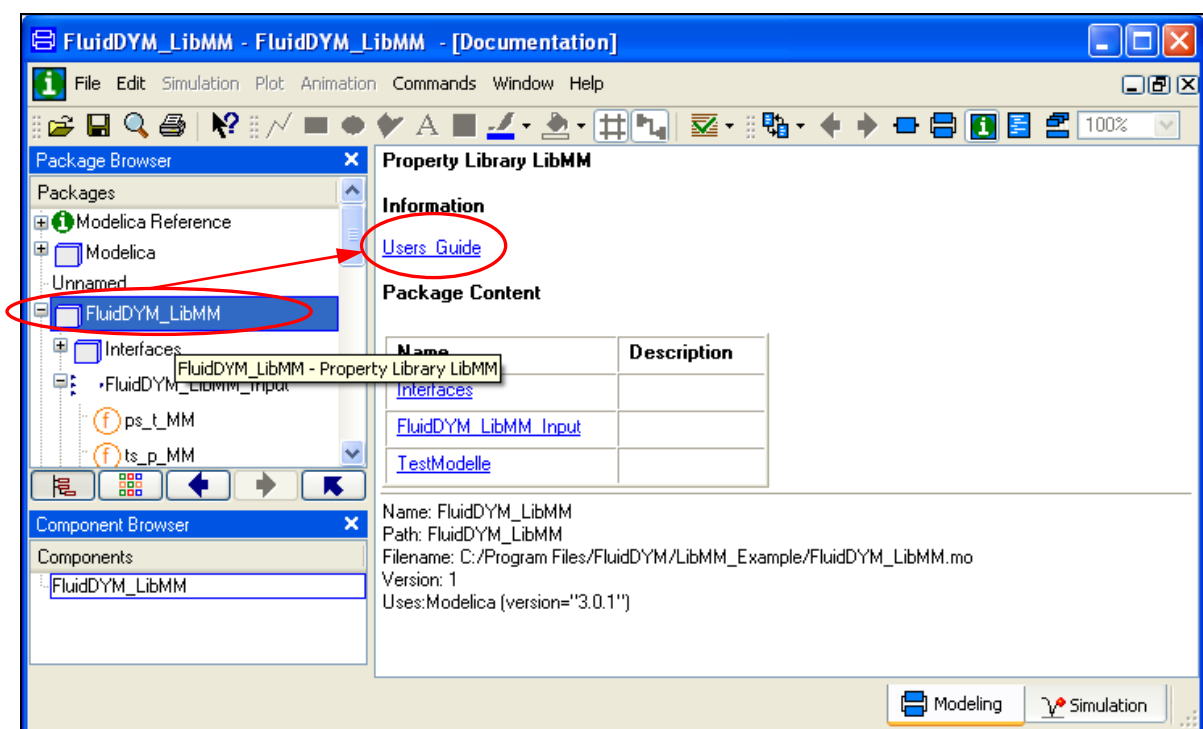


Figure 2.23: Selecting the "Users_Guide"

- 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_LibMM_Input" block on the left (see Figure 2.24).

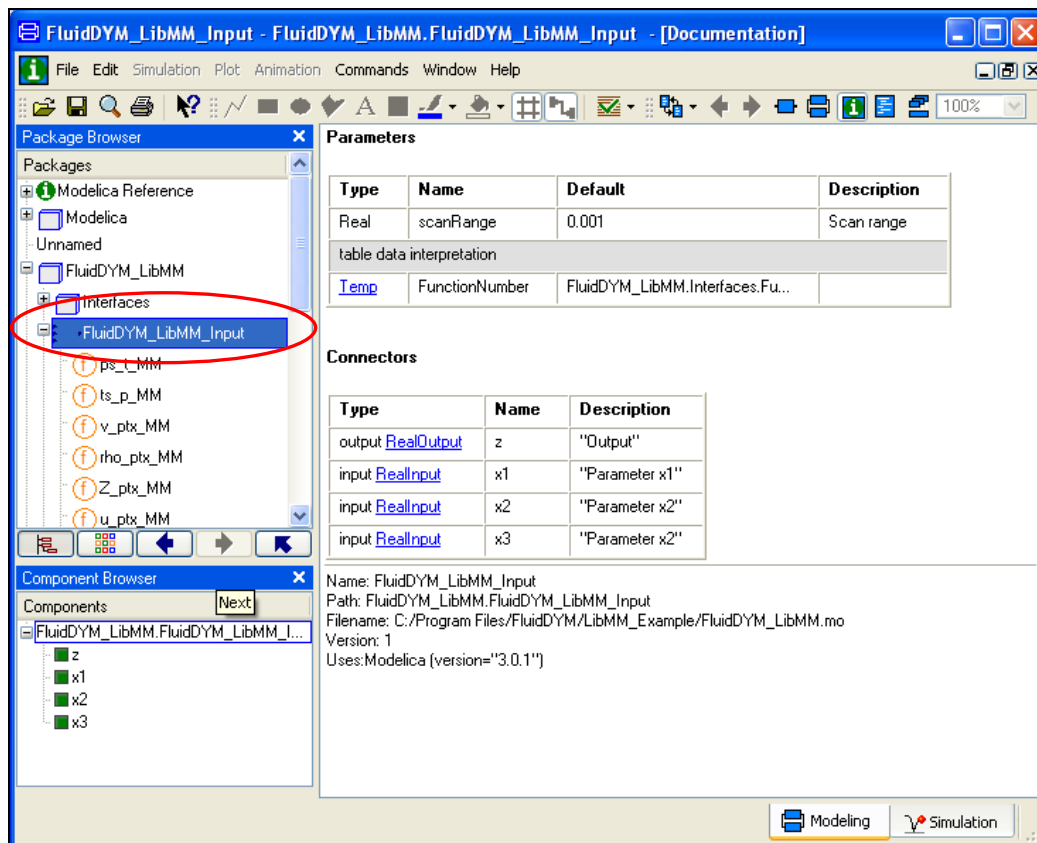


Figure 2.24: Selected "FluidDYM_LibMM_Input" Block

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

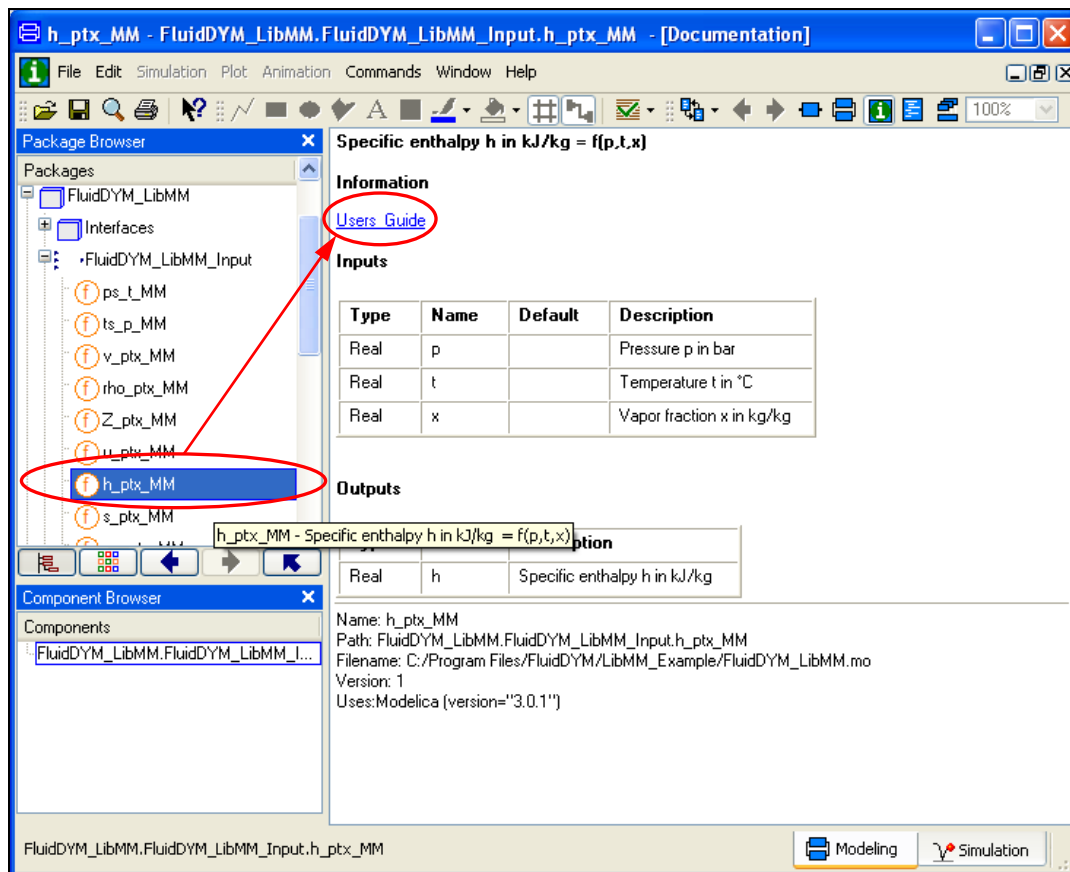


Figure 2.25: Marking the "h_ptx_MM" function and selecting the "Users_Guide"

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

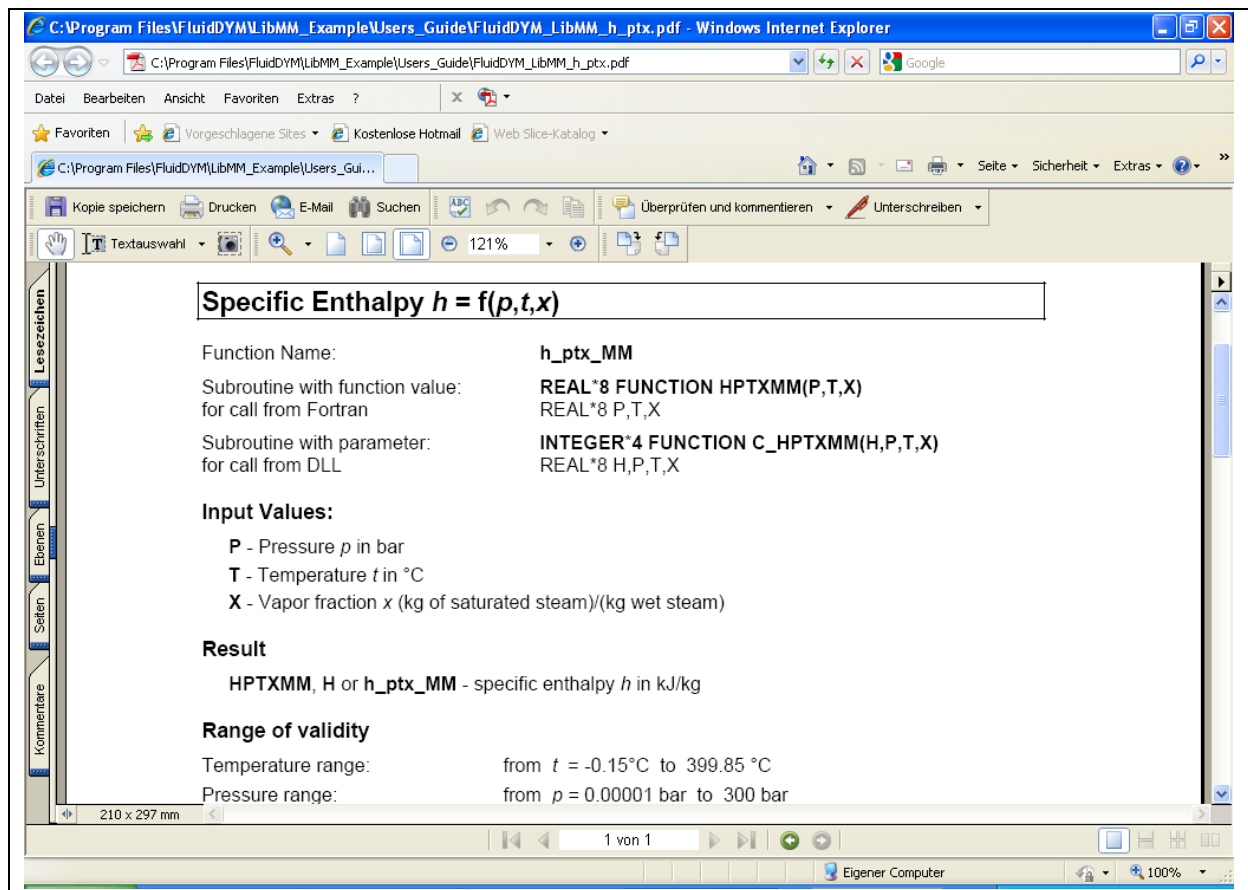


Figure 2.26: Help page of the function "h_ptx_MM" in the web browser

2.3 Removing LibMM in Dymola

In order to remove the property library LibMM 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 LibMM" 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 LibMM" has now been removed.

If LibMM 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_MM**

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

Subroutine with parameter:
for call from DLL **INTEGER*4 FUNCTION C_CPPTXMM(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

CPPTXMM, CP or **cp_ptx_MM** - specific isobaric heat capacity c_p in kJ/(kg K)

Range of validity

Temperature range: from $t = -0.15^\circ\text{C}$ 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 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.

Wet steam region: Temperature ranges from $t = -0.15^\circ\text{C}$ to $t_c = 245.6^\circ\text{C}$
 Pressure ranges from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Results for wrong input values

Result **CPPTXMM = -1000, CP = -1000** or **cp_ptx_MM = -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 $t < -0.15^\circ\text{C}$

Boiling or dew curve: at $p = -1000$ and $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$
 at $t = -1000$ and $p > p_c = 19.41004475$ bar
 or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar or
 at $p > p_c = 19.41004475$ bar or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar and
 $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$

References: [1]

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

Function Name: **cv_ptx_MM**

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

Subroutine with parameter:
for call from DLL **INTEGER*4 FUNCTION C_CVPTXMM(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

CVPTXMM, CV or **cv_ptx_MM** - specific isochoric heat capacity c_v in kJ/(kg K)

Range of validity

Temperature range: from $t = -0.15^\circ\text{C}$ 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 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.

Wet steam region: Temperature ranges from $t = -0.15^\circ\text{C}$ to $t_c = 245.6^\circ\text{C}$
 Pressure ranges from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Results for wrong input values

Result **CVPTXMM = -1000, CV = -1000** or **cv_ptx_MM = -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 $t < -0.15^\circ\text{C}$

Boiling or dew curve: at $p = -1000$ and $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$
 at $t = -1000$ and $p > p_c = 19.41004475$ bar
 or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar or
 at $p > p_c = 19.41004475$ bar or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar and
 $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$

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: **dpdtv_ptx_MM**

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

Subroutine with parameter: **INTEGER*4 FUNCTION C_DPDTVPTXMM(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

DPDTVPTXMM, DPDTV or dpdtv_ptx_MM - Derivative of pressure with respect to temperature (at constant specific volume) dpdtv in kPa/K

Range of validity

Temperature range: from $t = -0.15^\circ\text{C}$ 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 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 $t = -0.15^\circ\text{C}$ to $t_c = 245.6^\circ\text{C}$

Pressure ranges from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Results for wrong input values

Result **DPDTVPTXMM = -1000, DPDTV = -1000 or dpdtv_ptx_MM = -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 $t < -0.15^\circ\text{C}$

Boiling or dew curve: at $p = -1000$ and $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$
 at $t = -1000$ and $p > p_c = 19.41004475$ bar
 or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar or
 at $p > p_c = 19.41004475$ bar or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar and
 $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$

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_MM**
 Subroutine with function value: **REAL*8 FUNCTION DPDVTPTXMM(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**
 Subroutine with parameter: **INTEGER*4 FUNCTION C_DPDVTPTXMM(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

DPDVTPTXMM, DPDVT or dpdvt_ptx_MM - Derivative of pressure with respect to temperature (at constant temperature) dpdvt in kPa/(m³/kg)

Range of validity

Temperature range: from $t = -0.15^\circ\text{C}$ 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 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.

Wet steam region: Temperature ranges from $t = -0.15^\circ\text{C}$ to $t_c = 245.6^\circ\text{C}$
 Pressure ranges from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Results for wrong input values

Result **DPDVTPTXMM = -1000, DPDVT = -1000 or dpdvt_ptx_MM = -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 $t < -0.15^\circ\text{C}$

Boiling or dew curve: at $p = -1000$ and $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$
 at $t = -1000$ and $p > p_c = 19.41004475$ bar
 or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar or
 at $p > p_c = 19.41004475$ bar or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar and
 $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$

References: [1]

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

Function Name:	h_ptx_MM
Subroutine with function value: for call from Fortran	REAL*8 FUNCTION HPTXMM(P,T,X) REAL*8 P,T,X
Subroutine with parameter: for call from DLL	INTEGER*4 FUNCTION C_HPTXMM(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

HPTXMM, H or **h_ptx_MM** - specific enthalpy h in kJ/kg

Range of validity

Temperature range: from $t = -0.15^\circ\text{C}$ 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 two phase region (wet steam), either the value 0 or 1 has to be entered for x ($x = 0$ for boiling liquid, $x = 1$ for saturated steam). 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. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Wet steam region: Temperature ranges from $t = -0.15^\circ\text{C}$ to $t_c = 245.6^\circ\text{C}$
 Pressure ranges from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Results for wrong input values

Result **HPTXMM = -1000, H = -1000** or **h_ptx_MM = -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 $t < -0.15^\circ\text{C}$

Wet steam region: at $p = -1000$ and $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$
 at $t = -1000$ and $p > p_c = 19.41004475$ bar
 or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar or
 at $p > p_c = 19.41004475$ bar or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar and
 $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$

References: [1]

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

Function Name: **kappa_ptx_MM**
 Subroutine with function value: **REAL*8 FUNCTION KAPPAPTXMM(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**
 Subroutine with parameter: **INTEGER*4 FUNCTION C_KAPPAPTXMM(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

KAPPAPTXMM, KAPPA or kappa_ptx_MM - Isentropic exponent $\kappa = \frac{w^2}{p \cdot v}$

Range of validity

Temperature range: from $t = -0.15^\circ\text{C}$ 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 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 $t = -0.15^\circ\text{C}$ to $t_c = 245.6^\circ\text{C}$
 Pressure ranges from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Results for wrong input values

Result **KAPPAPTXMM, KAPPA = -1000** or **kappa_ptx_MM = -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 $t < -0.15^\circ\text{C}$

Boiling or dew curve: at $p = -1000$ and $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$
 at $t = -1000$ and $p > p_c = 19.41004475$ bar
 or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar or
 at $p > p_c = 19.41004475$ bar or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar and
 $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$

References: [1]

Vapor Pressure $p_s = f(t)$

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

Input Values:

T - Temperature t in °C

Result

PSTMM, PS or **ps_t_MM** - Vapor pressure p_s in bar

Range of validity

Temperature range: from $t = -0.15^\circ\text{C}$ to $t_c = 245.6^\circ\text{C}$

Results for wrong input values

Result **PSTMM = -1000, PS = -1000** or **ps_t_MM = -1000** for input values:

$t < -0.15^\circ\text{C}$ or $t > t_c = 245.6^\circ\text{C}$

References: [1]

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

Function Name: **rho_ptx_MM**

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

Subroutine with parameter:
for call from DLL **INTEGER*4 FUNCTION C_RHOPTXMM(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_MM, RHO or **rho_ptx_MM** - Density ρ in kg/m³

Range of validity

Temperature range: from $t = -0.15^\circ\text{C}$ 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 two phase region (wet steam), either the value 0 or 1 has to be entered for x ($x = 0$ for boiling liquid, $x = 1$ for saturated steam). 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. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Wet steam region: Temperature ranges from $t = -0.15^\circ\text{C}$ to $t_c = 245.6^\circ\text{C}$
 Pressure ranges from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Results for wrong input values

Result **RHOPTXMM = -1000, RHO = -1000** or **rho_ptx_MM = -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 $t < -0.15^\circ\text{C}$

Wet steam region: at $p = -1000$ and $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$
 at $t = -1000$ and $p > p_c = 19.41004475$ bar
 or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar or
 at $p > p_c = 19.41004475$ bar or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar and
 $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$

References: [1]

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

Function Name:	s_ptx_MM
Subroutine with function value: for call from Fortran	REAL*8 FUNCTION SPTXMM(P,T,X) REAL*8 P,T,X
Subroutine with parameter: for call from DLL	INTEGER*4 FUNCTION C_SPTXMM(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

SPTXMM, S or s_ptx_MM - Specific entropy s in kJ/kg K

Range of validity

Temperature range: from $t = -0.15^\circ\text{C}$ to 399.85°C

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 two phase region (wet steam), either the value 0 or 1 has to be entered for x ($x = 0$ for boiling liquid, $x = 1$ for saturated steam). 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. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Wet steam region: Temperature ranges from $t = -0.15^\circ\text{C}$ to $t_c = 245.6^\circ\text{C}$
 Pressure ranges from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Results for wrong input values

Result **SPTXMM = -1000, S = -1000 or s_ptx_MM = -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 $t < -0.15^\circ\text{C}$

Wet steam region: at $p = -1000$ and $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$
 at $t = -1000$ and $p > p_c = 19.41004475$ bar
 or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar or
 at $p > p_c = 19.41004475$ bar or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar and
 $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$

References: [1]

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

Function Name: **t_ph_MM**

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

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

Input Values:

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

Result

TPHMM, T or **t_ph_MM** - Temperature t in °C

Range of validity

Temperature range: from $t = -0.15^\circ\text{C}$ 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. That means the given values of p and h are taken as a basis and the subprogram will determine whether the state point to be calculated is located within the single-phase region (liquid or superheated steam) or the wet steam region. Afterwards the calculation of the appropriate state region will be carried out.

Wet steam region: Pressure ranges from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Results for wrong input values

Result **T_PH_MM, T = -1000** or **t_ph_MM = -1000** for input values:

Single phase region: $p > 300$ bar or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar or
 ($x = -1$) at result $t > 399.85^\circ\text{C}$, $t < -0.15^\circ\text{C}$

Boiling or dew curve: at $p > p_c = 19.41004475$ bar or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar
 at result $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$

References: [1]

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

Function Name: **t_ps_MM**

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

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

Input Values:

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

Result

TPSMM, T or **t_ps_MM** - Temperature t in °C

Range of validity

Temperature range: from $t = -0.15^\circ\text{C}$ 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. That means the given values of p and s are taken as a basis and the subprogram will determine whether the state point to be calculated is located within the single-phase region (liquid or superheated steam) or the wet steam region. Afterwards the calculation of the appropriate state region will be carried out.

Wet steam region: Pressure ranges from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Results for wrong input values

Result **T_PS_MM, T = -1000** or **t_ps_MM = -1000** for input values:

Single phase region: $p > 300$ bar or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar or
 ($x = -1$) at result $t > 399.85^\circ\text{C}$, $t < -0.15^\circ\text{C}$

Boiling or dew curve: at $p > p_c = 19.41004475$ bar or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar
 at result $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$

References: [1]

Boiling Temperature $t_s = f(p)$

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

Input Values:

P - Pressure p in bar

Result

TSPMM, TS or ts_p_MM - Boiling temperature t_s in °C

Range of validity

Pressure range: from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Results for wrong input values

Result **TSPMM = -1000, TS = -1000 or ts_p_MM = -1000** for input values:

$p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar or $p > p_c = 19.41004475$ bar

References: [1]

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

Function Name: **u_ptx_MM**

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

Subroutine with parameter:
for call from DLL **INTEGER*4 FUNCTION C_UPTXMM(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

UPTXMM, U or **u_ptx_MM** - Specific internal energy u in kJ/kg

Range of validity

Temperature range: from $t = -0.15^\circ\text{C}$ 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 two phase region (wet steam), either the value 0 or 1 has to be entered for x ($x = 0$ for boiling liquid, $x = 1$ for saturated steam). 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. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Wet steam region: Temperature ranges from $t = -0.15^\circ\text{C}$ to $t_c = 245.6^\circ\text{C}$
 Pressure ranges from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Results for wrong input values

Result **UPTXMM = -1000, U = -1000** or **u_ptx_MM = -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 $t < -0.15^\circ\text{C}$

Wet steam region: at $p = -1000$ and $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$
 at $t = -1000$ and $p > p_c = 19.41004475$ bar
 or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar or
 at $p > p_c = 19.41004475$ bar or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar and
 $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$

References: [1]

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

Function Name: **v_ptx_MM**

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

Subroutine with parameter: **INTEGER*4 FUNCTION C_VPTXMM(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

VPTXMM, V or v_ptx_MM - Specific volume v in m³/kg

Range of validity

Temperature range: from $t = -0.15^\circ\text{C}$ 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 two phase region (wet steam), either the value 0 or 1 has to be entered for x ($x = 0$ for boiling liquid, $x = 1$ for saturated steam). 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. If it is not the case the calculation for the quantity of the chosen function to be calculated results in -1000.

Wet steam region: Temperature ranges from $t = -0.15^\circ\text{C}$ to $t_c = 245.6^\circ\text{C}$
 Pressure ranges from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Results for wrong input values

Result **VPTXMM = -1000, V = -1000 or v_ptx_MM = -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 $t < -0.15^\circ\text{C}$

Wet steam region: at $p = -1000$ and $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$
 at $t = -1000$ and $p > p_c = 19.41004475$ bar
 or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar or
 at $p > p_c = 19.41004475$ bar or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar and
 $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$

References: [1]

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

Function Name: **w_ptx_MM**

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

Subroutine with parameter:
for call from DLL **INTEGER*4 FUNCTION C_WPTXMM(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

WPTXMM, W or **w_ptx_MM** - Speed of sound w in m/s

Range of validity

Temperature range: from $t = -0.15^\circ\text{C}$ 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 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 $t = -0.15^\circ\text{C}$ to $t_c = 245.6^\circ\text{C}$
 Pressure ranges from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Results for wrong input values

Result **WPTXMM = -1000, W = -1000** or **w_ptx_MM = -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 $t < -0.15^\circ\text{C}$

Wet steam region: at $p = -1000$ and $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$
 at $t = -1000$ and $p > p_c = 19.41004475$ bar
 or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar or
 at $p > p_c = 19.41004475$ bar or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar and
 $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$

References: [1]

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

Function Name:	x_ph_MM
Subroutine with function value: for call from Fortran	REAL*8 FUNCTION XPHMM(P,H) REAL*8 P,H
Subroutine with parameter: for call from DLL	INTEGER*4 FUNCTION C_XPHMM(X,P,H) REAL*8 X,P,H

Input Values:

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

Result

XPHMM, X or x_ph_MM - Vapor fraction x in (kg saturated steam/kg wet steam)

Range of validity

Temperature range: from $t = -0.15^\circ\text{C}$ to $t_c = 245.6^\circ\text{C}$
 Pressure range: from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Details on the calculation of wet steam

The wet steam region is calculated automatically. That means the given values of p and h are taken as a basis and the subprogram will determine whether the state point to be calculated is located within the single-phase region (liquid or superheated steam) or the wet steam region. In case of wet steam, x will be calculated, otherwise the result is set to $x = -1$.

Wet steam region: Pressure ranges from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Results for wrong input values

Result **X_PH_MM, X = -1** or **x_ph_MM = -1** for input values:

In case the point of state is located in the single phase region:
 $p > p_c = 19.41004475$ bar or $p < 0.01316986$ bar

References: [1]

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

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

Input Values:

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

Result

XPSMM, X or x_ps_MM - Vapor fraction x in (kg saturated steam/kg wet steam)

Range of validity

Temperature range: from $t = -0.15^\circ\text{C}$ to $t_c = 245.6^\circ\text{C}$
 Pressure range: from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Details on the calculation of wet steam

The wet steam region is calculated automatically. That means the given values of p and s are taken as a basis and the subprogram will determine whether the state point to be calculated is located within the single-phase region (liquid or superheated steam) or the wet steam region. In case of wet steam, x will be calculated, otherwise the result is set to $x = -1$.

Wet steam region: Pressure ranges from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Results for wrong input values

Result **X_PS_MM, X = -1** or **x_ps_MM = -1** for input values:

In case the point of state is located in the single phase region:
 $p > p_c = 19.41004475$ bar or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar

References: [1]

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

Function Name: **Z_ptx_MM**

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

Subroutine with parameter:
for call from DLL **INTEGER*4 FUNCTION C_ZPTXMM(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

ZPTXMM, Z or Z_ptx_MM - Compression factor

Range of validity

Temperature range: from $t = -0.15^\circ\text{C}$ to 399.85°C

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 $t = -0.15^\circ\text{C}$ to $t_c = 245.6^\circ\text{C}$

Pressure ranges from $p_s(-0.15^\circ\text{C}) = 0.01316986$ bar to $p_c = 19.41004475$ bar

Results for wrong input values

Result **ZPTXMM = -1000, Z = -1000 or Z_ptx_MM = -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 $t < -0.15^\circ\text{C}$

Boiling or dew curve: at $p = -1000$ and $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$
 at $t = -1000$ and $p > p_c = 19.41004475$ bar
 or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar or
 at $p > p_c = 19.41004475$ bar or $p < p_s(-0.15^\circ\text{C}) = 0.01316986$ bar and
 $t > t_c = 245.6^\circ\text{C}$ or $t < -0.15^\circ\text{C}$

References: [1]

Water and Steam	Humid Combustion Gas Mixtures	Humid Air
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 LibHuGas Ideal mixture of the real fluids: CO₂ - Span and Wagner O₂ - Schmidt and Wagner H₂O - IAPWS-95 Ar - Tegeler et al. N₂ - Span et al. and of the ideal gases: SO₂, CO, Ne (scientific equations of Bückner et al.) Consideration of Dissociation from VDI 4670 and Poynting effect Library LibIDGAS Ideal gas mixture calculated from the VDI-Guideline 4670	Library LibHuAir Ideal mixture of the real fluids: - Dry air from Lemmon et al. - Steam and water from IAPWS-IF97 Consideration of - Dissociation from VDI-Guideline 4670 - Poynting effect Library LibIdAir Ideal gas mixture calculate from VDI-Guideline 4670

Carbon Dioxide	Ideal Gas Mixtures	Seawater
Library LibCO2 Formulation of Span and Wagner (1994)	Library LibIdGasMix Ideal mixture of the ideal gases: Ar SO₂ Methane Ne H₂ Ethane N₂ H₂S Ethylene O₂ OH Propylene CO He Propane CO₂ F₂ Iso-Butane Air NH₃ n-Butane NO Benzene H₂O Methanol Consideration of - Dissociation from VDI-Guideline 4670	Library LibSeaWa IAPWS Formulation (2008) and IAPWS-IF97
Hydrogen		Refrigerant R134a
Library LibH2 Formulation of Leachman et al. (2007)		Library LibR134a Formulation of Tillner-Roth and Baehr (1994)
Helium		Refrigerant NH3
Library LibHe Formulation of McCarty and Arp (1990)		Library LibNH3 Formulation of Tillner-Roth (1995)
Methanol		
Library LibCH3OH Formulation of de Reuck and Craven (1993)		

ORC Working Fluids	Mixtures for Absorption Processes	Refrigerants
Library LibMM Siloxane C₆H₁₈OSi₂ (MM) Formulation of Colonna et al. (2006) Library LibD4 Siloxane C₈H₂₄O₄Si₄ (D4) Formulation of Colonna et al. (2006) Library LibD5 Siloxane C₁₀H₃₀O₅Si₅ (D5) Formulation of Colonna et al. (2006) Library LibMD4M Siloxane C₁₄H₄₂O₅Si₆ (MD4M) Formulation of Colonna et al. (2006)	Library LibAmWa Ammonia/Water Mixtures IAPWS Guideline 2005 of Tillner-Roth and Friend (1998) Helmholtz energy formulation for the mixing term Library LibWaLi Water/Lithium Bromide Mixtures Formulation of Kim and Infante Ferreira (2004) Gibbs energy equation for the mixing term	Library LibPropan Refrigerant Propane Formulation of Lemmon et al. (2008) Library LibButan_Iso Refrigerant Iso-Butane Formulation of Bückner et al. (2003) Library LibButan_n Refrigerant n-Butane Formulation of Bückner et al. (2003)

Using the Add-In FluidEXL a direct call of the property functions in Excel® is possible.

Function in FluidEXL

	h	v
	kJ/kg	m³/kg
3248.23	0.1512	
3054.14	0.2585	
2888.54	0.4404	
2589.27	1.6298	
2480.74	3.0090	
2258.57	12.6755	

The Add-In FluidEES allows to call the functions of the property libraries within the Engineering Equation Solver EES®.

Function in FluidEES

```

"Calculating the Specific Enthalpy of Sea Water"

p=1 "Pressure p in bar"
t=100 "Temperature t in °C"
Xi=0.12 "Water mass fraction of sea salt in kg/kg"

CALL h_ptx_97(p,t,Xi,h)
  
```

Add-In FluidMAT for Mathcad®

Using the Add-on FluidMAT, the functions of the property libraries can be used in Mathcad®.

Function in FluidMAT

Calculation of Specific Enthalpy of Steam from IAPWS-IF97

$p := 10$ in bar given pressure

$t := 300$ in °C given temperature

$x := -1$ in $\frac{\text{kg}}{\text{kg}}$ vapor fraction (-1 for single phase region)

$h := h_ptx_97(p, t, x)$ call of the function from FluidMAT

$h = 3051.70$ in $\frac{\text{kJ}}{\text{kg}}$ result for specific enthalpy

Add-In FluidLAB for MATLAB®

The property functions can be called in MATLAB®.

Function in FluidLAB

```

1 hl_ptxw_HuAir.m
2 %%
3 p=1; % pressure in bar
4 t=20; % temperature in °C
5 xw=10; % absolute humidity in g/kg air
6 %%
7 hl=hl_ptxw_HuAir(p,t,xw)
8 %%
  
```

The following thermodynamic and transport properties can be calculated¹:

Thermodynamic Properties

- Saturation 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

Thermodynamic Derivatives

- Partial derivatives can be calculated

Transport Properties

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

Backward Functions

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

For information please contact:

Zittau/Goerlitz University of Applied Sciences
Department of Technical Thermodynamics
Prof. Hans-Joachim Kretzschmar
Dr. Ines Stoecker
Theodor-Koerner-Allee 16
02763 Zittau, Germany

E-mail: hj.kretzschmar@hs-zigr.de
Internet: www.thermodynamics-zittau.de
Phone: +49-3583-61-1846
Fax.: +49-3583-61-1846

¹ Not all of these property functions are available in all property libraries listed before.

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: 12/2008

The following companies and institutions use the property libraries in Excel®, MATLAB®, Mathcad®, Engineering Equation Solver®, and/or DYMOLA®:

1997

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

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
EVO, Energieversorgung Offenbach (Offenbach Energy Utilities Company)	11/1998

1999

Bayernwerk Munich (power supply company)	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

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 Erkrath Engineering	04/2000
SaarEnergie Saarbruecken	05/2000, 08/2001
DVO Data Processing Service Oberhausen	05/2000
Aachen University of Applied Sciences	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 (toolbuilding) Barsbuettel (general license for training test benches)	11/2000
Steinhaus Informationssysteme Datteln (general license for process data software)	12/2000

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 (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 (energy systems), Freising	09/2001
Electrowatt-EKONO Zurich, Switzerland	09/2001

IPM Zittau (general license)	10/2001
eta Energieberatung Pfaffenhofen	11/2001
ALSTOM Power Baden, Switzerland	12/2001
VEAG Berlin (group license)	12/2001,
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 (public utilities company)	08/2002
Stadtwerke Hannover (public utilities company)	09/2002
Siemens Power Generation Goerlitz	10/2002
Energieversorgung (Energy Utilities Company) Halle (company license)	10/2002
Bayer Leverkusen	11/2002
Dillinger Huette (iron works) Dillingen	11/2002
G.U.N.T. Geraetebau (toolbuilding) Barsbuettel (general license and training test benches)	12/2002
VEAG Berlin (group license)	12/2002

2003

Utzenstorf Paper Factory, 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 (energy consulting, planning) Winterthur, Switzerland	02/2003
DLR Leupholdhausen	04/2003
Emden University of Applied Sciences, Department of Technology	05/2003
Pettersson+Ahrends Ober-Moerlen	05/2003
SOFBID Zwingenberg (general EBSILON program license)	05/2003
Ostendorf Engineering 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 Nuernberg	11/2003
Visteon Kerpen	11/2003
VEO Vulkan Energiewirtschaft (energy management) Oderbruecke Eisenhuettenstadt	11/2003
Stadtwerke Hannover (public utilities company)	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 (company license)	12/2003
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 (energy systems) Freising	07/2004
FCIT Stuttgart	08/2004
Physikalisch Technische Bundesanstalt (PTB) Braunschweig	08/2004
Mainova Frankfurt	08/2004
Rietschle Energieplaner (energy consulting, planning) Winterthur, Switzerland	08/2004
MAN Turbo Machines Oberhausen	09/2004
TUEV Sued Dresden	10/2004
STEAG Kraftwerk (power plant) 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

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 (power engineering, company license)	02/2005, 04/2005, 07/2005
eta Energieberatung (energy consulting) Pfaffenhofen	02/2005
FZR Forschungszentrum (Research Center) Rossendorf/Dresden	04/2005
University of Saarbruecken	04/2005
Technical University of Dresden	
Professorship of Thermic Energy Machines and Plants	04/2005
Grenzebach BSH Bad Hersfeld	04/2005
TUEV Nord Hamburg	04/2005
Technical University of Dresden, Waste Management	05/2005
Siemens Power Generation Goerlitz	05/2005
Duesseldorf University of Applied Sciences, Department of Mechanical Engineering and Process Engineering	05/2005
Redacom Nidau, Switzerland	06/2005
Dumas Verfahrenstechnik Hofheim	06/2005
Alensys Engineering Erkner	07/2005
Stadtwerke Leipzig (public utilities company)	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 (energy provider; company license)	12/2005
KEMA IEV Dresden	12/2005

2006

STORA ENSO Sachsen Eilenburg	01/2006
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Technical University of Munich, Chair in Energy Systems	01/2006
NUTEC Engineering Bisikon, Switzerland	01/2006, 04/2006
Conwel eco Bochoy, Czech Republic	01/2006
Offenburg University of Applied Sciences	01/2006
KOCH Transporttechnik Wadgassen (transportation technology)	01/2006
BEG Bremerhavener Entsorgungsgesellschaft (waste disposal company)	02/2006
Deggendorf University of Applied Sciences, Department of Mechanical Engineering and Mechatronics	02/2006
University of Stuttgart, Department of Thermal Fluid Flow Engines	02/2006
Technical University of Munich, Chair in Apparatus and Plant Engineering	02/2006
Energietechnik Leipzig (energy technology), (company license)	02/2006
Siemens Power Generation Erlangen	02/2006, 03/2006
RWE Power Essen	03/2006
WAETAS Pobershau	04/2006
Siemens Power Generation Goerlitz	04/2006
Technical University of Braunschweig, Department of Thermodynamics	04/2006
EnviCon & Plant Engineering Nuernberg	04/2006
Brassel Engineering, Dresden	05/2006
University of Halle-Merseburg, Department of USET Merseburg incorporated society	05/2006
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	05/2006
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	05/2006
Suedzucker Ochsenfurt (sugar manufacturing)	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

2007

Audi Ingolstadt	02/2007
ANO Abfallbehandlung Nord Bremen (waste treatment)	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 (Armed Forces University)	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 (building services)	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
Technical University of Aachen, Institute for Electrophysics (registered society)	09/2007
National Energy Technology Laboratory Pittsburg, USA	10/2007

Energieversorgung Halle (energy supplier)	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 (measurement and test engineering)	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

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, Professorship of Building Services	07/2008
Technical University of Cottbus, Chair in Power Plant Engineering	07/2008, 10/2008
Ingersoll-Rand Unicov, Czech Republic	08/2008
Technip Benelux BV Zoetermeer, Netherlands	08/2008
Fennovoima Oy Helsinki, Finland	08/2008
Fichtner Consulting & IT Stuttgart	09/2008
PEU Espenhain	09/2008

Poyry Dresden	09/2008
WINGAS Kassel	09/2008
TUEV Sued Dresden	10/2008
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	10/2008, 11/2008
AWTEC Zurich, Switzerland	11/2008
Siemens Power Generation Erlangen	12/2008