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Property Library for Dodecamethyl-pentasiloxane (MD3M) $C_{12}H_{36}Si_5O_4$

FluidLAB
with LibMD3M
for MATLAB®

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Property Library for the Calculation of Dodecamethylpentasiloxane (MD3M)

FluidLAB for MATLAB®
LibMD3M

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0. Package Contents

Zip-file "CD_FluidLAB_LibMD3M.zip" including the following files:

FluidLAB_LibMD3M_Setup.exe	- Installation program for the FluidLAB Add-On for use in MATLAB®
LibMD3M.dll	- DLL with functions of the LibMD3M library

<u>Documentation</u>

FluidLAB_LibMD3M_Docu_Eng.pdf	- User's Guide

1. Property Functions

1.1 Calculation Programs

"MD3M" means Dodecamethylpentasiloxane **($C_{12}H_{36}Si_5O_4$)**

Functional Dependence	Function Name	Call from Fortran program	Call in DLL LibMD3M as parameter	Property or Function	Unit of the result
$c_p = f(p,t,x)$	cp_ptx_MD3M	CPPTXMD3M(P,T,X)	C_CPPTXMD3M(CP,P,T,X)	Specific isobaric heat capacity	kJ/(kg K)
$c_v = f(p,t,x)$	cv_ptx_MD3M	CVPTXMD3M(P,T,X)	C_CVPTXMD3M(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_MD3M	DPDTVMD3M(P,T,X)	C_DPDTVMD3M(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_MD3M	DPDVTMD3M(P,T,X)	C_DPDVTMD3M(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_MD3M	HPTXMD3M(P,T,X)	C_HPTXMD3M(H,P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p,t,x)$	kappa_ptx_MD3M	KAPPAPTXMD3M(P,T,X)	C_KAPPAPTXMD3M(KAPPA,P,T,X)	Isentropic exponent	-
$p_s = f(t)$	ps_t_MD3M	PSTMD3M(T)	C_PSTMD3M(PS,T)	Vapor pressure from temperature	bar
$\rho = f(p,t,x)$	rho_ptx_MD3M	RHOPTXMD3M(P,T,X)	C_RHOPTXMD3M(RHO,P,T,X)	Density	kg/m³
$s = f(p,t,x)$	s_ptx_MD3M	SPTXMD3M(P,T,X)	C_SPTXMD3M(S,P,T,X)	Specific entropy	kJ/(kg K)
$t = f(p,h)$	t_ph_MD3M	TPHMD3M(P,H)	C_TPHMD3M(T,P,H)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p,s)$	t_ps_MD3M	TPSMD3M(P,S)	C_TPSMD3M(T,P,S)	Backward function: Temperature from pressure and entropy	°C
$t_s = f(p)$	ts_p_MD3M	TSPMD3M(P)	C_TSPMD3M(TS,P)	Saturation temperature from pressure	°C
$u = f(p,t,x)$	u_ptx_MD3M	UPTXMD3M(P,T,X)	C_UPTXMD3M(U,P,T,X)	Specific internal energy	kJ/kg
$v = f(p,t,x)$	v_ptx_MD3M	VPTXMD3M(P,T,X)	C_VPTXMD3M(V,P,T,X)	Specific volume	m³/kg
$w = f(p,t,x)$	w_ptx_MD3M	WPTXMD3M(P,T,X)	C_WPTXMD3M(W,P,T,X)	Isentropic speed of sound	m/s
$x = f(p,h)$	x_ph_MD3M	XPHMD3M(P,H)	C_XPHMD3M(X,P,H)	Backward function: Vapor fraction from pressure and enthalpy	kg/kg

Functional Dependence	Function Name	Call from Fortran program	Call in DLL LibMD3M as parameter	Property or Function	Unit of the result
x = f(p,s)	x_ps_MD3M	XPSMD3M(P,S)	C_XPSMD3M(X,P,S)	Backward function: Vapor fraction from pressure and entropy	kg/kg
Z = f(p,t,x)	Z_ptx_MD3M	ZPTXMD3M(P,T,X)	C_ZPTXMD3M(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°C to 400 °C
Pressure range: from p = 0.0000048971 bar to 300 bar

Reference state

h = 0 kJ/kg and s = 0 kJ/(kg K) at t_B = 229.88 °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.

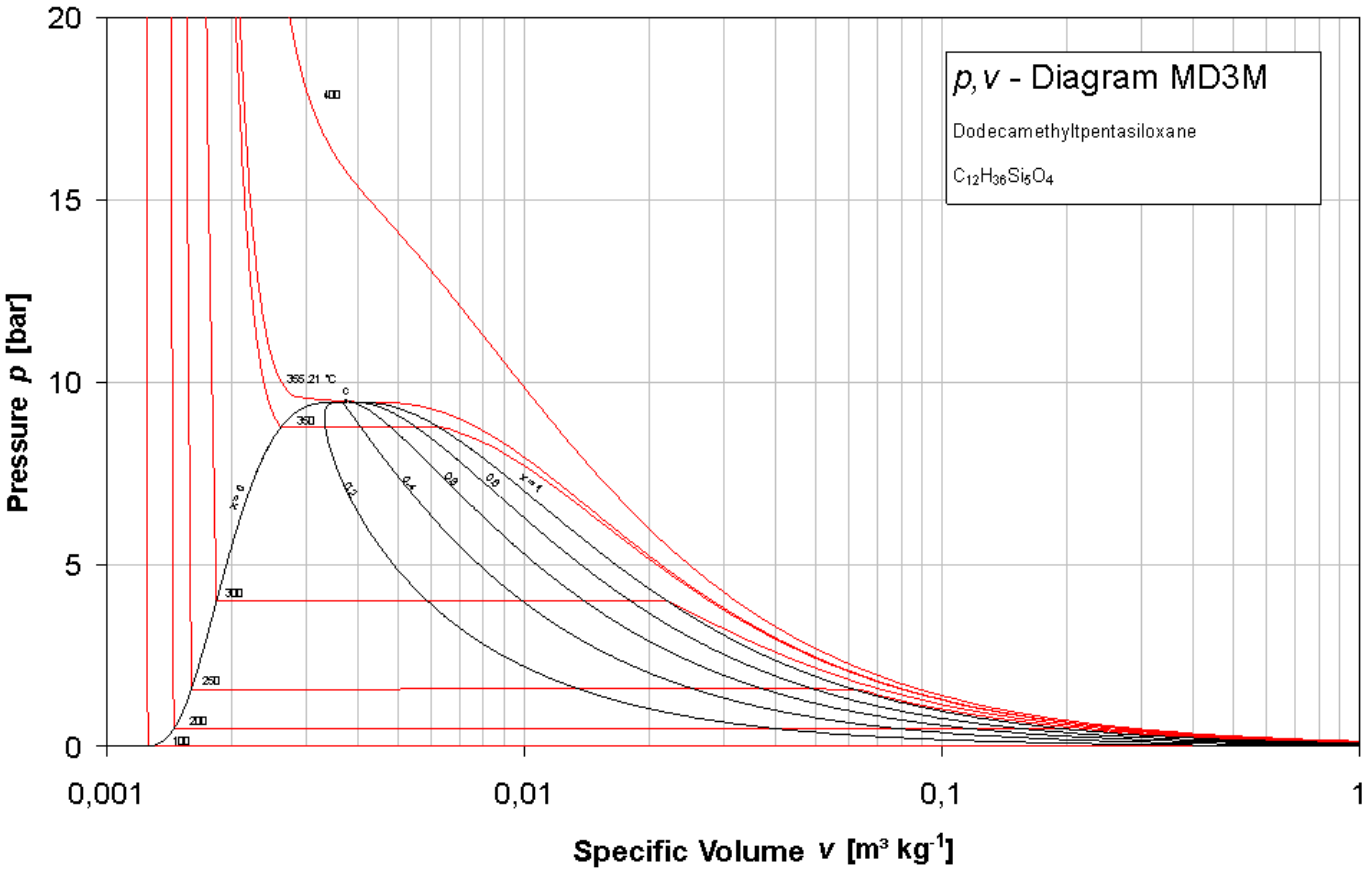
If *p* and *t* and *x* are entered as given values, the program considers *p* and *t* to be appropriate to represent the vapor pressure curve. If this is not the case the calculation for the property of the chosen function results in –1000.

Wet steam region: Temperature range from t = 0 °C to t_c = 355.21 °C
Pressure range from p_s (0 °C) = 0.00078994 bar to p_c = 9.45229 bar

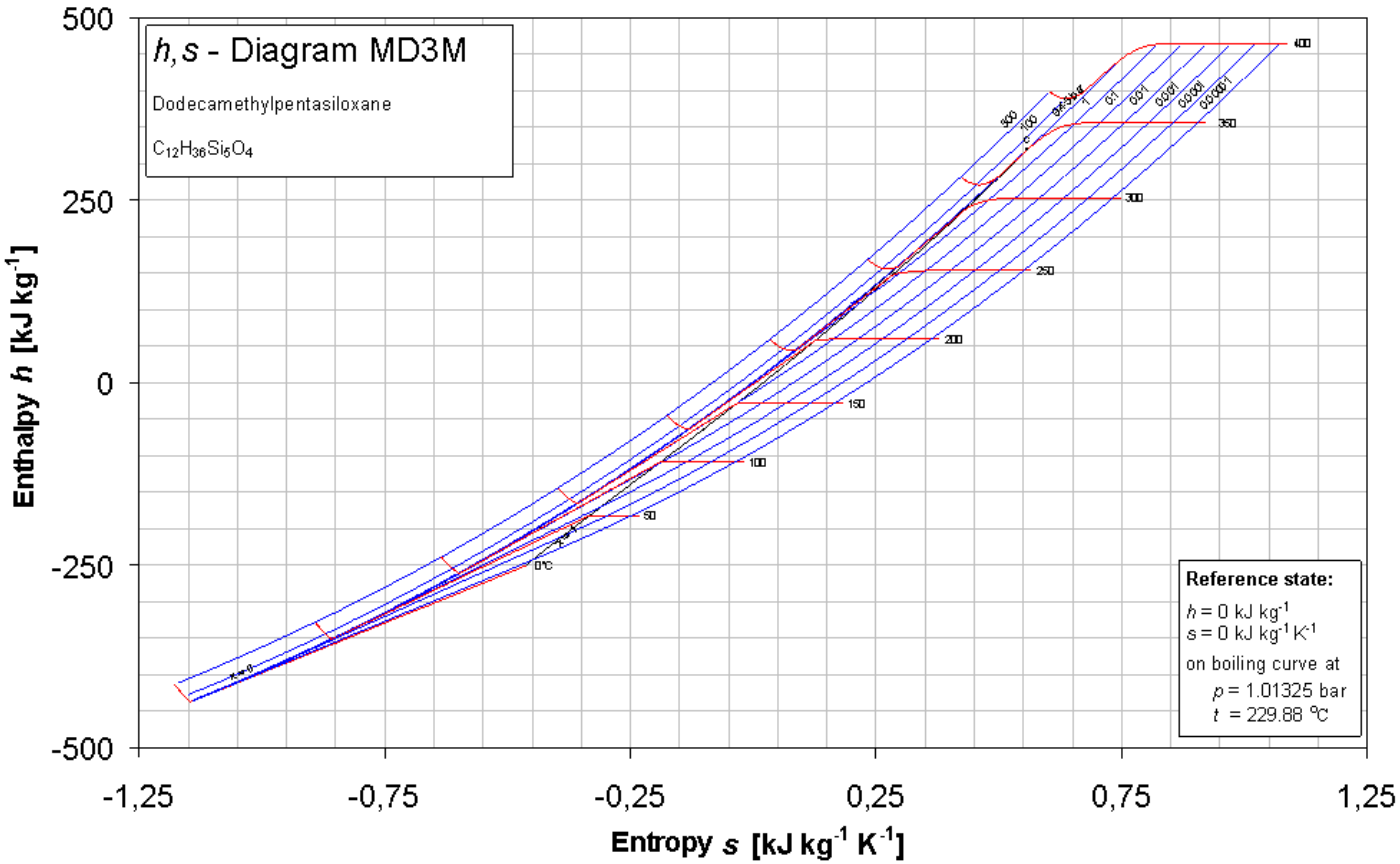
Note.

If the calculation results in –1000, the values entered represent a state point beyond the range of validity of MD3M. 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.

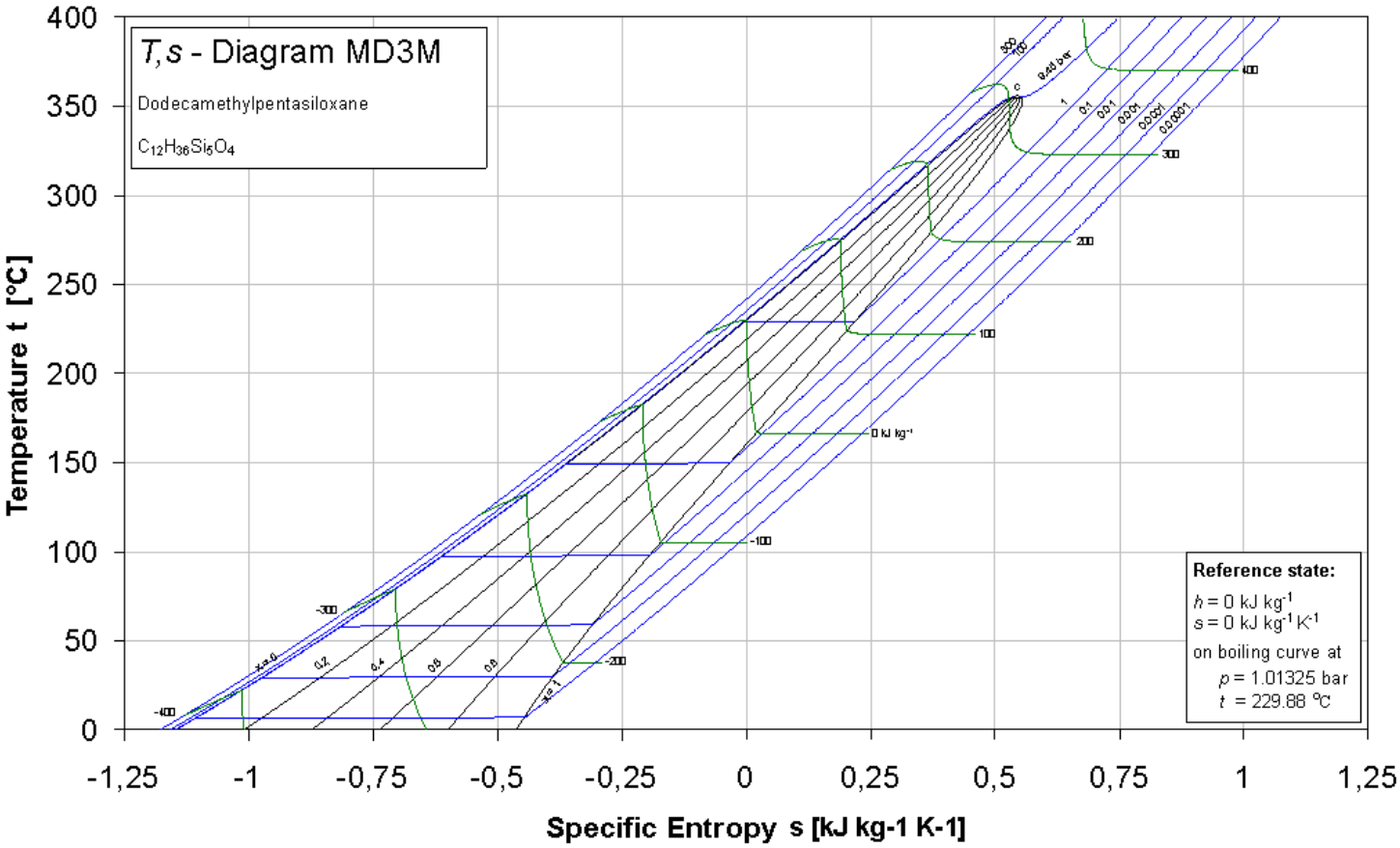
1.2 p,v-Diagram



1.3 h,s-Diagram



1.4 T,s-Diagram



2 Application of FluidLAB in MATLAB®

The FluidLAB Add-In has been developed to calculate thermodynamic properties in MATLAB® more conveniently. Within MATLAB® it enables the direct call of functions relating to Dodecamethylpentasiloxane from the LibMD3M property library.

2.1 Installing FluidLAB including LibMD3M

This section describes the installation of FluidLAB including the LibMD3M property library.

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

After you have downloaded and extracted the zip-file "CD_FluidLAB_LibMD3M.zip", you will see the folder

CD_FluidLAB_LibMD3M

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

Open this folder by double-clicking on it.

In this folder you will see the following three files:

FluidLAB_LibMD3M_Docu_Eng.pdf
FluidLAB_LibMD3M_Setup.exe
LibMD3M.dll.

In order to run the installation of FluidLAB including the LibMD3M property library, double-click on the file

FluidLAB_LibMD3M_Setup.exe.

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

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

C:\Program Files\FluidLAB\LibMD3M

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

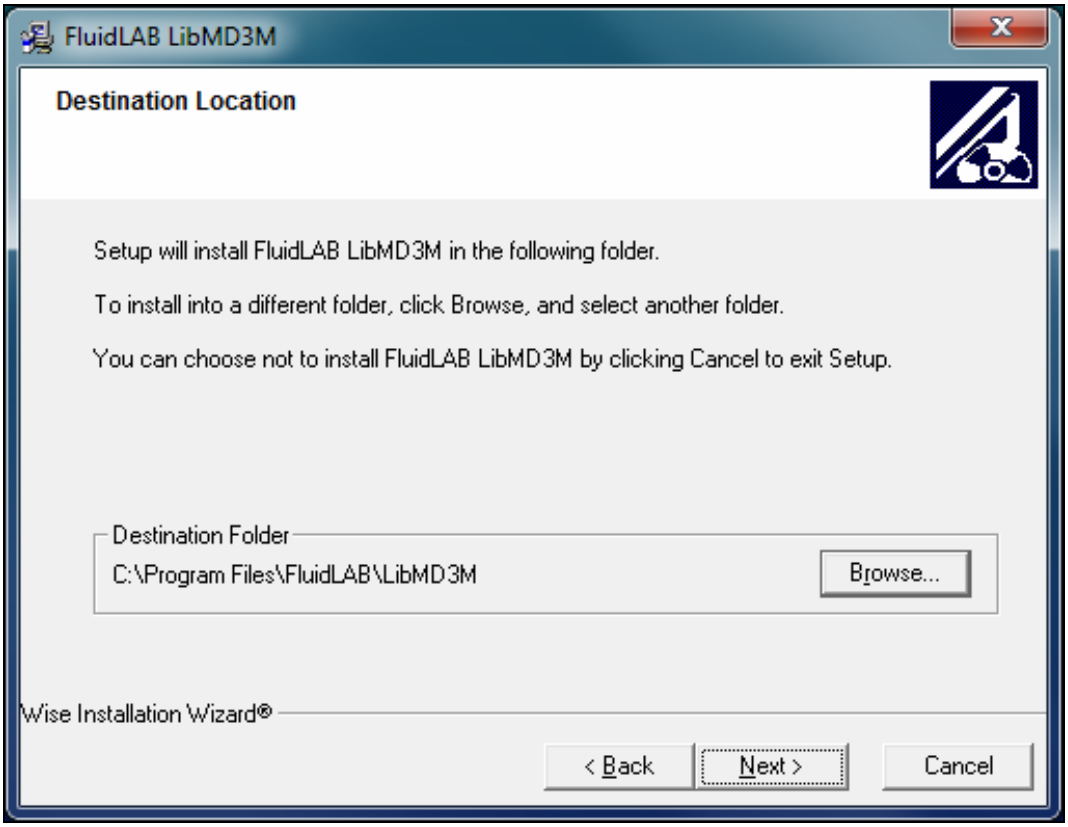


Figure 2.1: "Destination Location"

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

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

The installation program has copied the following files for LibMD3M into the directory "C:\Program Files\FluidLAB\LibMD3M":

advapi32.dll	LibMD3M.dll
Dformd.dll	msvcp60.dll
Dforrt.dll	msvcrt.dll
INSTALL.LOG	Unwise.exe
LC.dll	Unwise.ini

- MATLAB®-Interface-Program for calculable functions

cp_ptx_MD3M	t_ph_MD3M
cv_ptx_MD3M	t_ps_MD3M
dpdtv_ptx_MD3M	ts_p_MD3M
dpdvt_ptx_MD3M	u_ptx_MD3M
h_ptx_MD3M	v_ptx_MD3M
Kappa_ptx_MD3M	w_ptx_MD3M
ps_t_MD3M	x_ph_MD3M
rho_ptx_MD3M	x_ps_MD3M
s_ptx_MD3M	Z_ptx_MD3M

Now, you have to overwrite the file "LibMD3M.dll" in your FluidLAB directory with the file of the same name provided on your CD with FluidLAB.

To do this, open the CD in "My Computer" and click on the file "LibMD3M.dll" in order to highlight it.

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

Now, open your FluidLAB directory (the standard being C:\Program Files\FluidLAB\LibMD3M) and insert the file "LibMD3M.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 "LibMD3M.dll" successfully and the property functions are available in MATLAB®.

Licensing the LibMD3M Property Library

The licensing procedure must be carried out when the prompt message appears. In this case, you will see the "License Information" window for LibMD3M (see figure below).

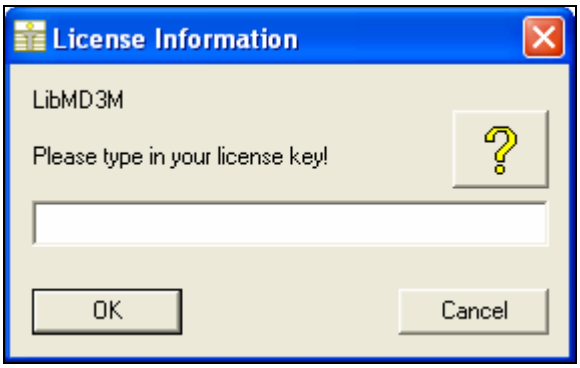


Figure 2.2: "License Information" window

Here you are asked to type in the license key which you have obtained from the Zittau/Goerlitz University of Applied Sciences. If you do not have this, or have any questions, you will find contact information on the "Content" page of this User's Guide or by clicking the yellow question mark in the "License Information" window. Then the following window will appear:

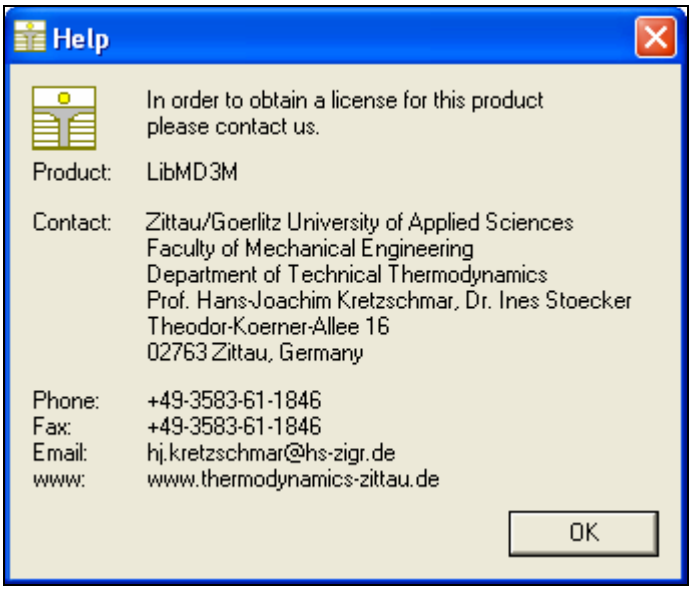


Figure 2.3: "Help" window

If you do not enter a valid license it is still possible to use MATLAB® by clicking "Cancel". In this case, the LibMD3M property library will display the result "–11111111" for every calculation.

The "License Information" window will appear every time you use FluidLAB LibMD3M until you enter a license code to complete registration. If you decide not to use FluidLAB LibMD3M, you can uninstall the program following the instructions given in section 2.4 of this User's Guide.

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

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

Please carry out the following instructions:

- Start Windows Explorer®, Total Commander®, My Computer or another file manager program. The following description refers to Windows Explorer®.
- Your Windows Explorer® should be set to "Details" for easier viewing. Click the "Views" button and select "Details."
- Switch into the program directory of FluidLAB, in which you will find the folder "\LibMD3M"; it is generally saved under: "C:\Program Files\FluidLAB"
- Create the folder "\LibMD3M_Example" by clicking on "File" in the Explorer® menu, then "New" in the menu which appears and afterwards selecting "Folder". Name the new folder "\LibMD3M_Example."
- You will now see the following window:

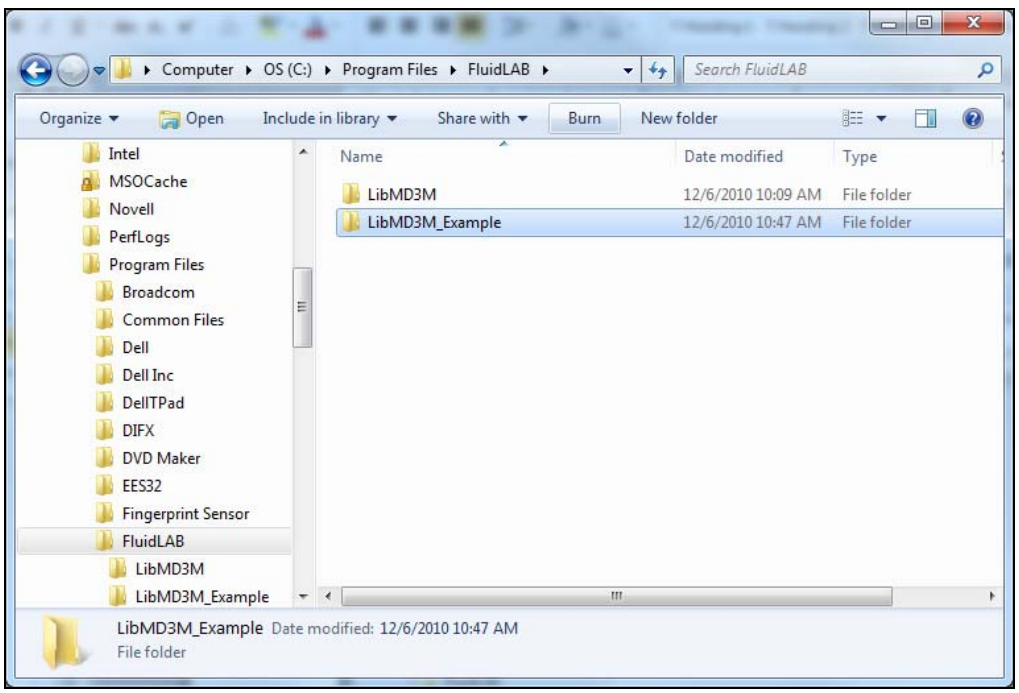


Figure 2.4: Folders "LibMD3M" and "LibMD3M_Example"

- Switch into the directory "\LibMD3M" within "\FluidLAB", the standard being "C:\Program Files\FluidLAB\LibMD3M."

- You will see the following window:

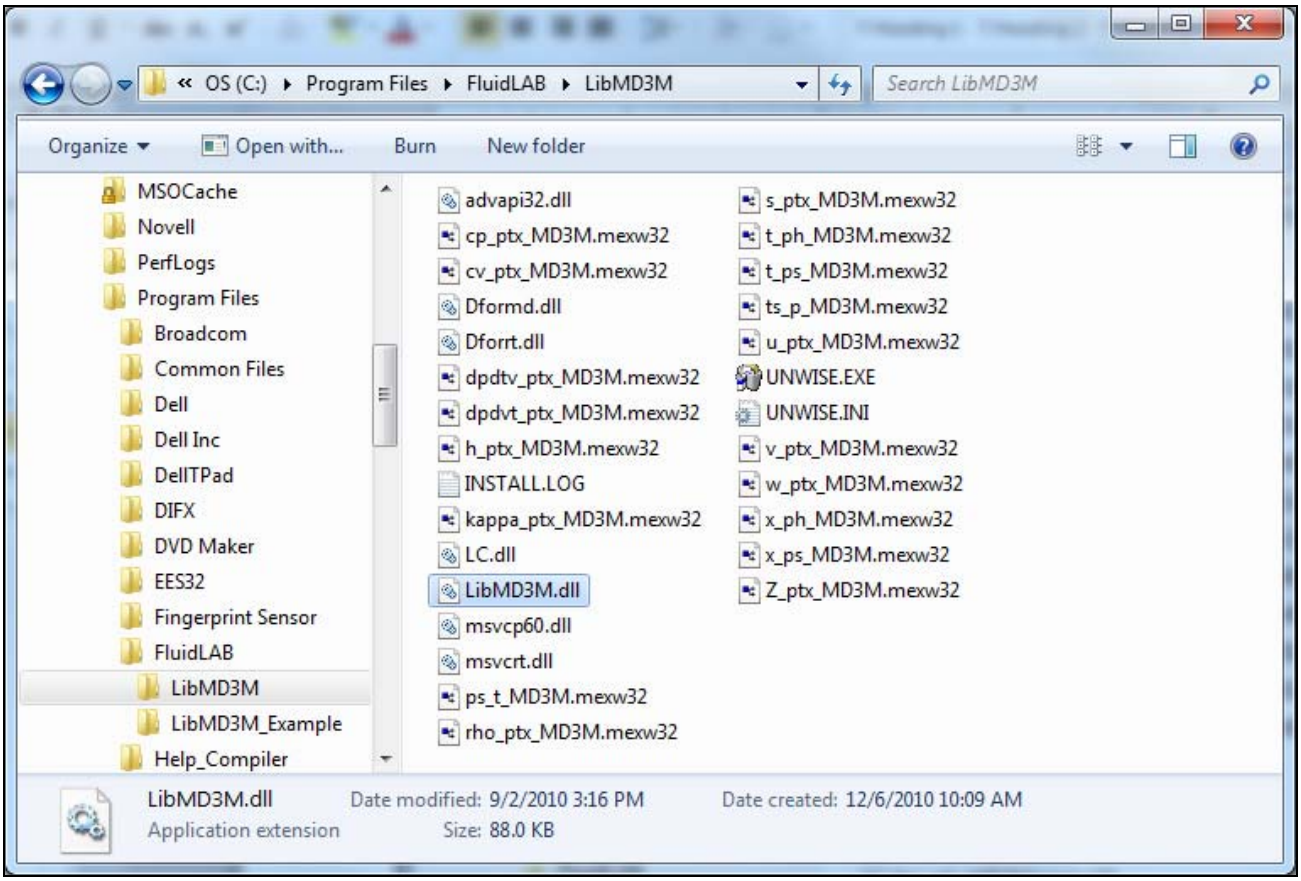


Figure 2.5: Contents of the folder "LibMD3M"

You will now have to copy the following files into the directory "C:\Program Files\FluidLAB\LibMD3M_Example" in order to calculate the function $h = f(p,t,x)$.

- The following eight files are needed:
    - "advapi32.dll"
    - "Dformd.dll"
    - "Dforrt.dll"
    - "h_ptx_MD3M.mexw32"
    - "LC.dll"
    - "LibMD3M.dll"
    - "msvcp60.dll"
    - "msvcrt.dll."
- Click the file "h_ptx_MD3M.mexw32", then click "Edit" in the upper menu bar and select "Copy".
- Switch into the directory "C:\Program Files\FluidLAB\LibMD3M_Example", click "Edit" and then "Paste".
- Repeat these steps in order to copy the other files listed above. You may also select all the

above-named files and then copy them as a group (press the Control button to enable multiple markings).

- You will see the following window:

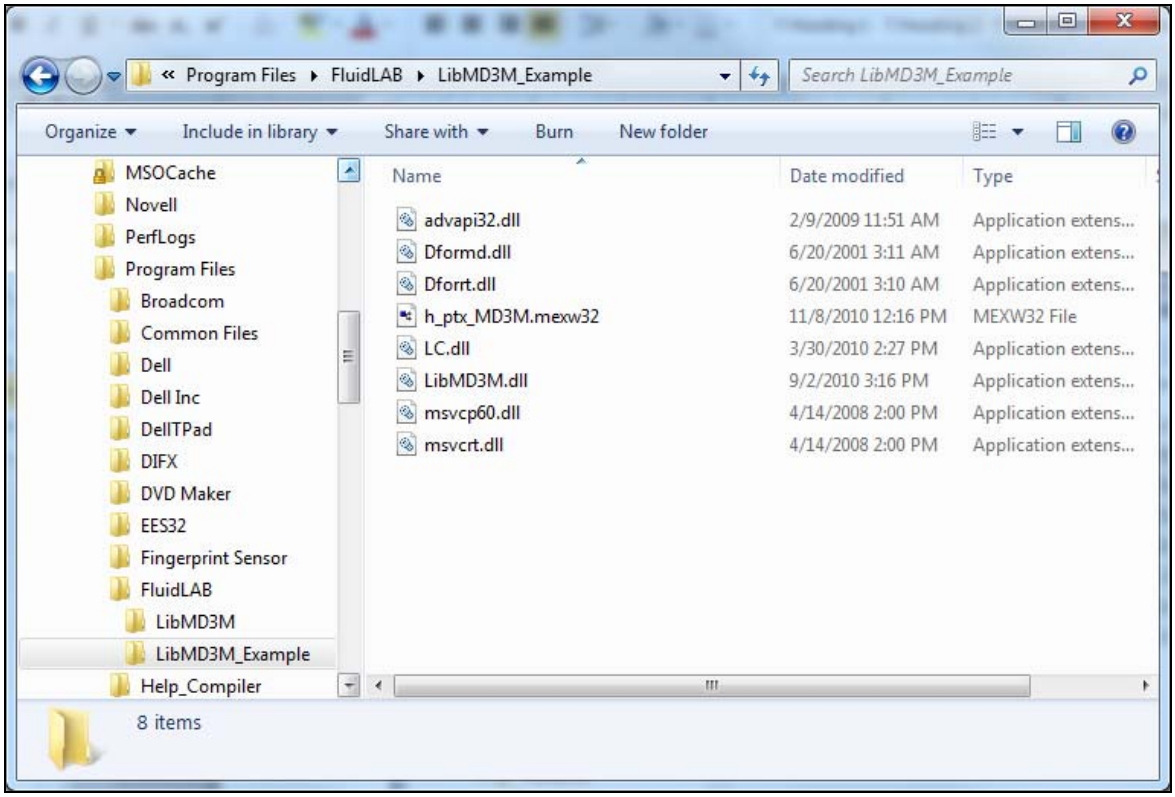


Figure 2.6: Contents of the folder "LibMD3M_Example"

- Start MATLAB® (if you have not started it before).
- Click the button marked in the next figure in order to open the folder "\LibMD3M_Example" in the "Current Folder" window.

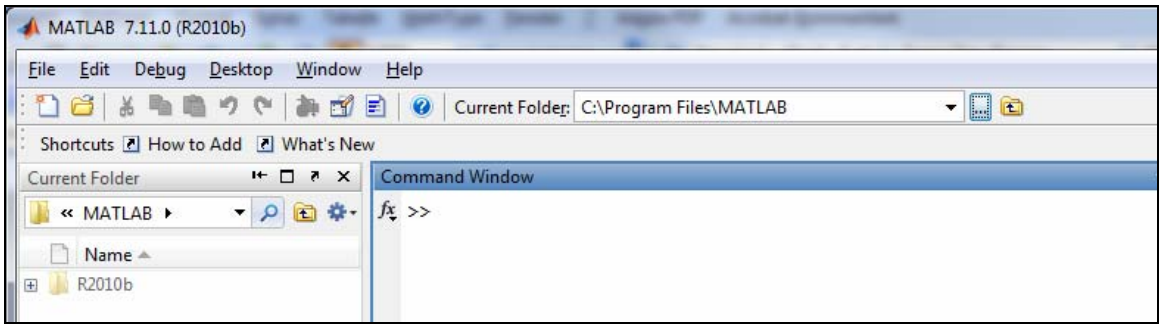


Figure 2.7: Selection of the working directory

- Find and select the directory "C:\Program Files\FluidLAB\LibMD3M_Example" in the pop-up menu (see the following image).

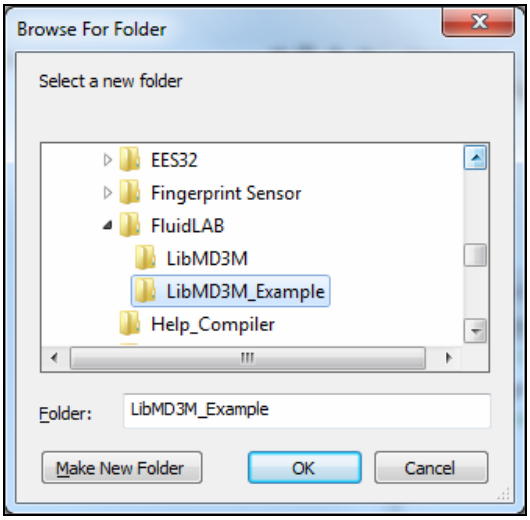


Figure 2.8: Choosing the "LibMD3M_Example" folder

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

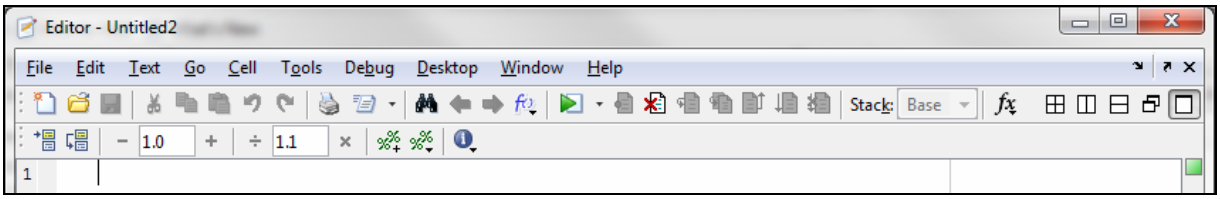


Figure 2.9: Embedding the "Editor" window

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

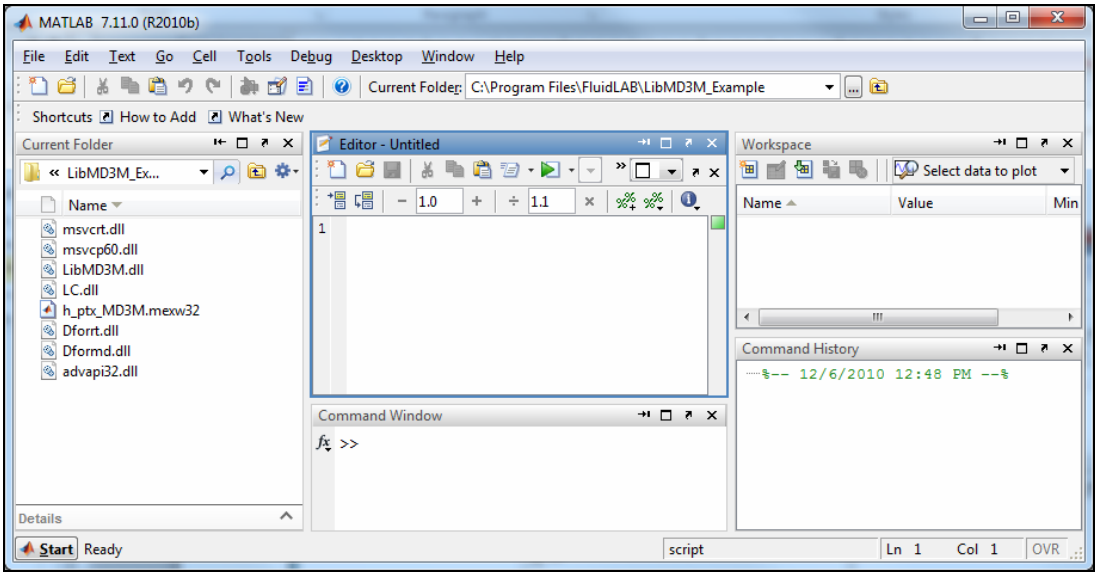


Figure 2.10: Embedded "Editor" window

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

Text to be written:	Explanation:
`% h_ptx_MD3M.m`	file name as comment
`%%`	paragraph separation
`p=10; % pressure in bar`	declaration of the variables pressure, temperature, art and composition of mixture
`t=300; % temperature in °C`	
`x=-1; % vapor fraction in kg/kg`	
`%%`	paragraph separation
`h=h_ptx_MD3M(p,t,x)`	function call
`%%`	paragraph separation

- Remarks:

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

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

- First operand: Value for p = 10
  (Range of validity: p = 0.00001 bar to 300 bar)
- Second operand: Value for t = 300 °C
  (Range of validity: t = 26.85°C to 399.85 °C)
- Third operand: Value for x = -1 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 when the value for *x* is entered:

<u>Single-phase region</u>

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

<u>Wet-steam region</u>

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

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

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

(MD3M Saturation pressure curve:

t = 0 °C to t_C = 355.21 °C

p_S(0 °C) = 0.00078994 bar to p_C = 9.45229 bar)

- Save the "M-File" by clicking the "File" button and then click "Save As...".
- The menu "Save file as:" appears; In this menu, the folder name "LibMD3M_Example" must be displayed in the "Save in:" field.
- Next to "File name" you have to type "Example_h_ptx_MD3M.m" and afterwards click the "Save" button.

Note.
The name of the example file has to be different in comparison to the name of the used function. For example, the file could not be named "h_ptx_MD3M.m" in this case. Otherwise an error message will appear during the calculation.

- You will now see the following window:

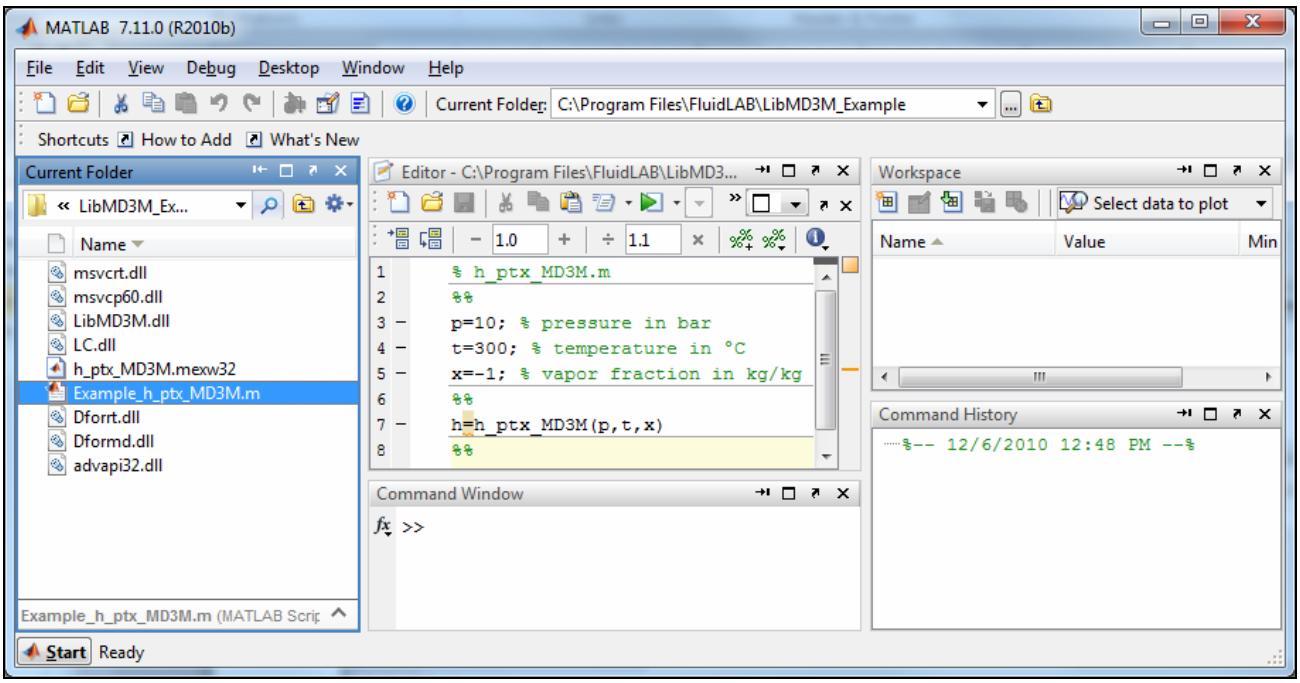


Figure 2.11: "Example_h_ptx_MD3M.m" M-file

- Within the "Current Folder" window, the file "Example_h_ptx_MD3M.m" appears.
- Right-click on this file and select "Run" in the menu which appears (see next image).

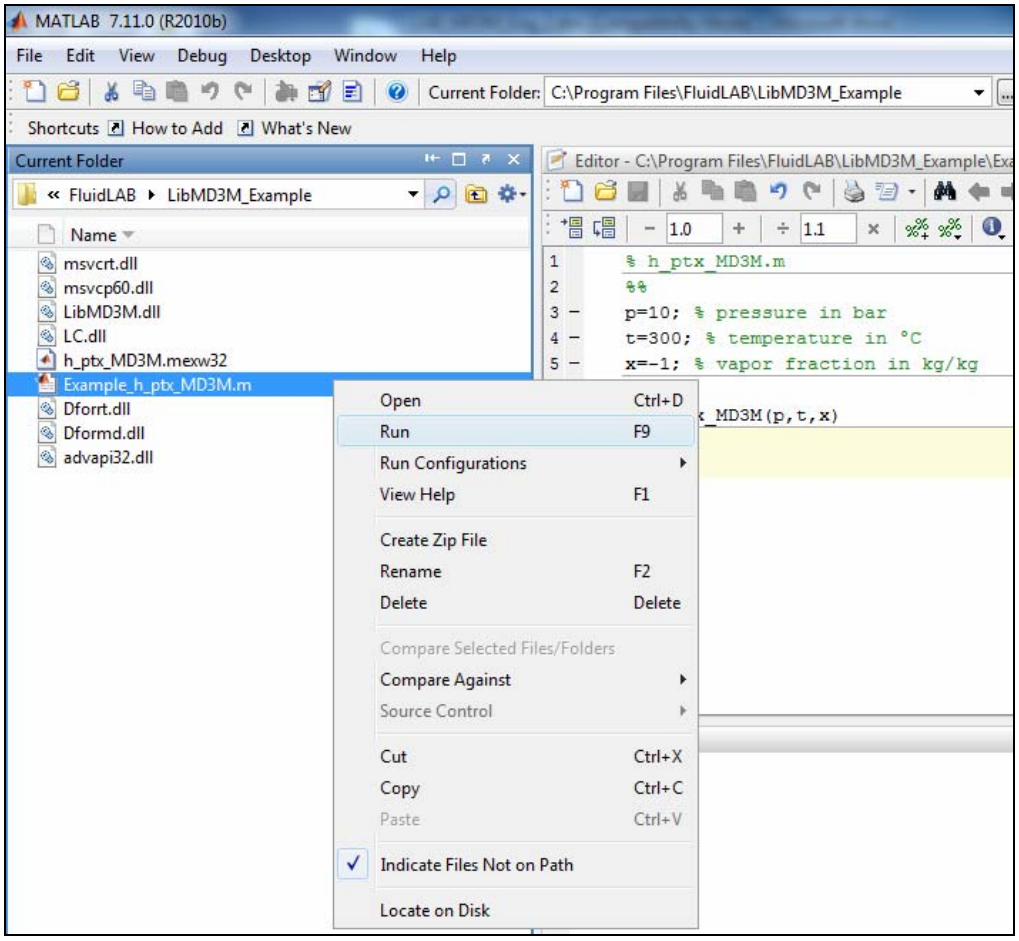


Figure 2.12: Running the "Example_h_ptx_MD3M.m" M-file

- You will see the following window:

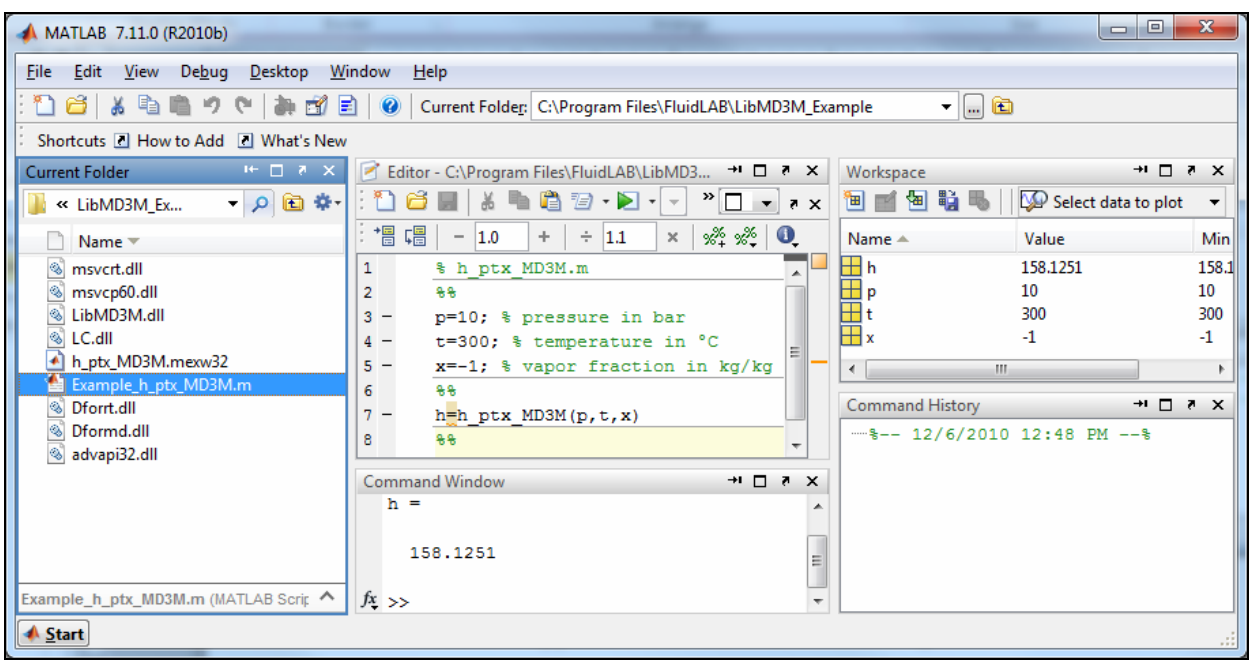


Figure 2.13: MATLAB® with calculated result

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

⇒ The result in our sample calculation here is: "h = 158.1251". The corresponding unit is kJ/kg (see table of the property functions in Chapter 1).

To be able to calculate other values, you have to copy the associated mexw32 files as well because MATLAB® can only access functions that are located in the "Current Directory" window. The example calculated can be found in the directory C:\Program Files\FluidLAB\LibMD3M_Example," and you may use it as a basis for further calculations using FluidLAB.

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

- Start MATLAB® (if you have not started it already).
- Click the button marked in the following image in order to open the folder "\LibMD3M_Example" in the window "Current Folder."

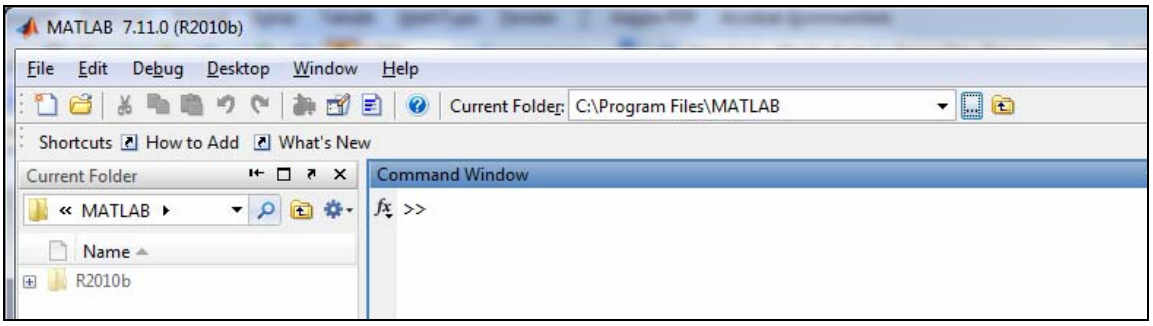


Figure 2.14: Selection of the working directory

- Find and select the directory "C:\Program Files\FluidLAB\LibMD3M_Example" in the pop-up menu (see the following image).

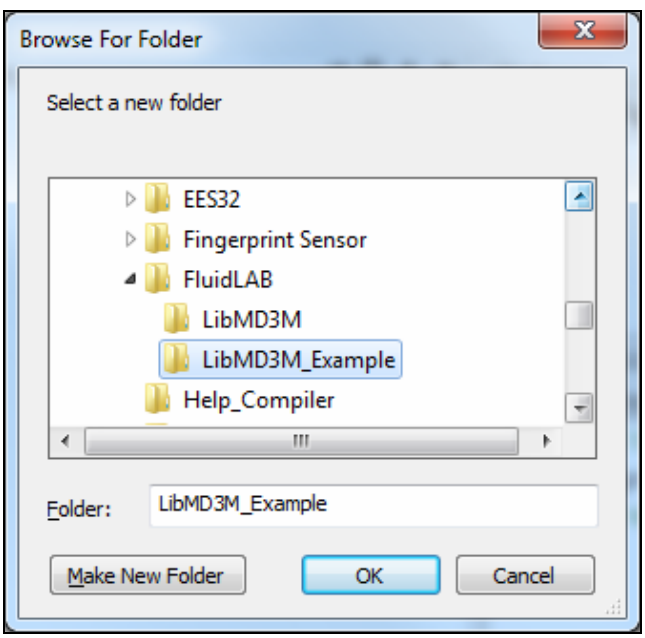


Figure 2.15: Choosing the "LibMD3M_Example" folder

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

- You will see the following window:

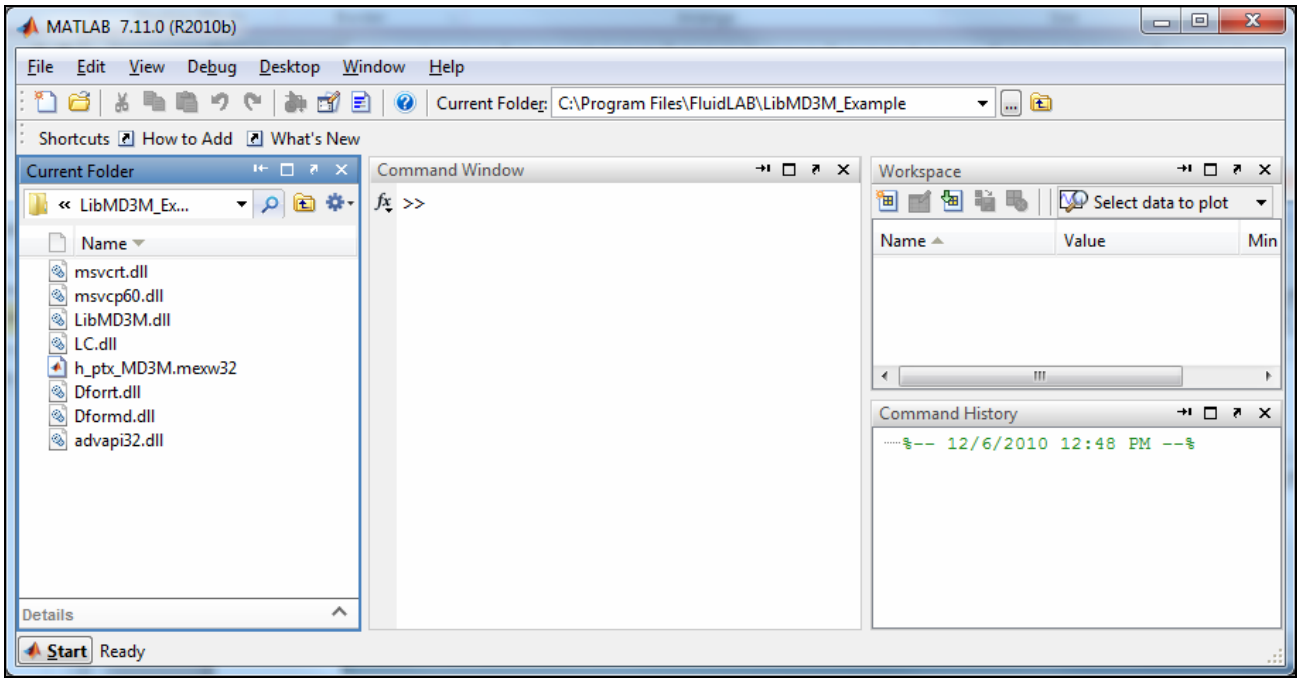


Figure 2.16: MATLAB® with necessary files

Corresponding to the table of the property functions in Chapter 1 you have to call up the function "**h_ptx_MD3M**" as follows for calculating $h = f(p,t,x)$.

Write "**h=h_ptx_MD3M(10,300,-1)**" within the "Command Window"

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

- First operand: Value for p = 10 bar
  (Range of validity: p = 0.00001 bar to 300 bar)
- Second operand: Value for t = 300 °C
  (Range of validity: t = 26.85°C to 399.85 °C)
- Third operand: Value for x = -1

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

<u>Single-phase region</u>

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

<u>Wet-steam region</u>

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

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

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

(MD3M Saturation pressure curve:

t = 0 °C to t_C = 355.21 °C

p_S(0 °C) = 0.00078994 bar to p_C = 9.45229 bar)

- Confirm your entry by pressing the "ENTER" button.

- You will see the following window:

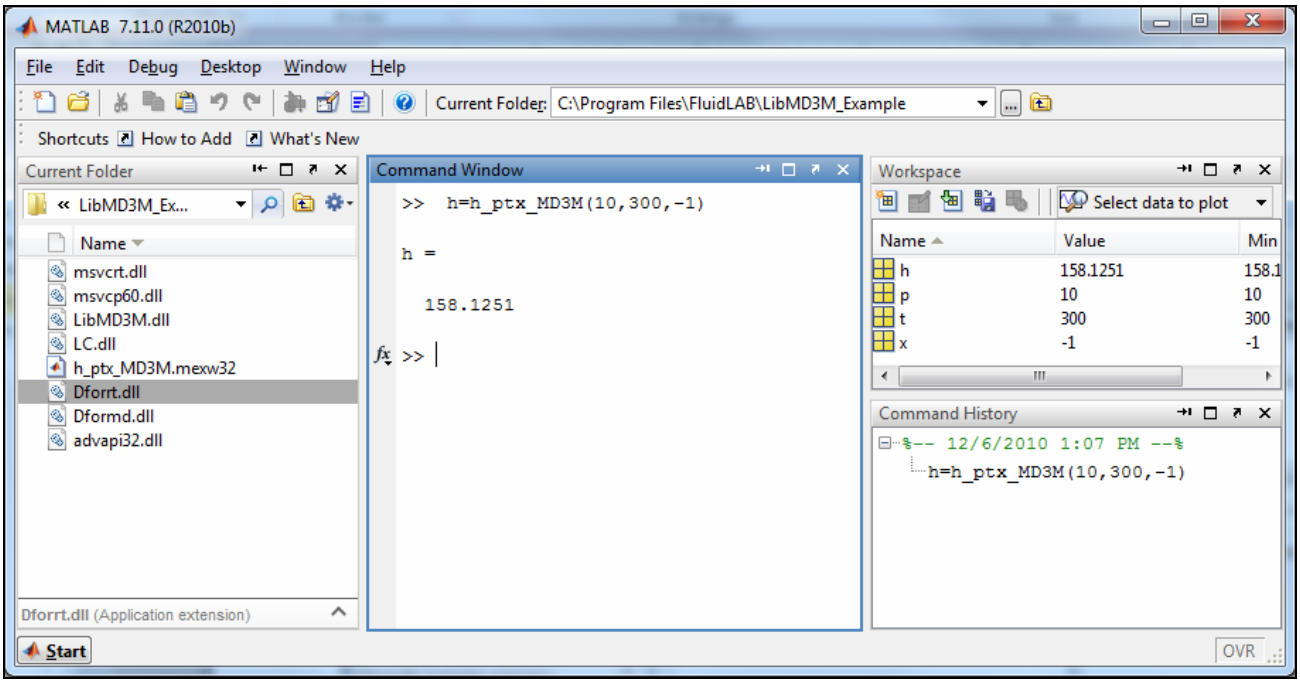


Figure 2.17: MATLAB® with calculated result

⇒ In the "Command Window" you will see the result "h = 158.1251". The corresponding unit is kJ/kg (see table of the property functions in Chapter 1).

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

2.2.4 Removing FluidLAB including LibMD3M

To remove the property library LibMD3M from your hard disk drive in Windows®, click "Start" in the Windows® task bar, select "Settings" and click "Control Panel".
Now double-click on "Add or Remove Programs". In the list box of the "Add or Remove Programs" window that appears select "FluidLAB LibMD3M" by clicking on it and click the "Change/Remove" button.
In the following dialog box click "Automatic" and then click the "Next >" button.
Confirm the following menu "Perform Uninstall" by clicking the "Finish" button.
Finally, close the "Add or Remove Programs" and "Control Panel" windows. Now, FluidLAB has been removed.

If there is no library other than LibMD3M installed, the directory "FluidLAB" will be removed as well.

3. Program Documentation

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

Function Name:	**cp_ptx_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION CPPTXMD3M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_CPPTXMD3M(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

CPPTXMD3M, CP or **cp_ptx_MD3M** – specific isobaric heat capacity c_p in kJ/(kg K)

Range of validity

Temperature range:	from t = 0°C to 400°C
Pressure range:	from p = 0.0000048971 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.

Saturated liquid and	Temperature ranges from $t = 0°C$ to $t_c = 355.21°C$
saturated vapor line:	Pressure ranges from $p_s(0°C) = 0.0000048971$ bar to $p_c = 9.45229$ bar

Results for wrong input values

Result **CPPTXMD3M = -1000**, **CP = -1000** or **cp_ptx_MD3M = -1000** for input values:

Single phase region: (x = -1)	p > 300 bar or p < 0.0000048971 bar or t > 400 °C or t < 0°C
Saturation lines:	at $p = -1000$ and $t > t_c = 355.21°C$ to $t < 0°C$ at $t = -1000$ and $p > p_c = 9.451229$ bar or $p < p_s(0°C) = 0.0000048971$ bar or or $p > p_c = 9.45229$ bar or $p < p_s(0°C) = 0.0000048971$ bar and $t > t_c = 355.21°C$ or $t < 0°C$

References: [1], [2]

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

Function Name:	**cv_ptx_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION CVPTXMD3M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_CVPTXMD3M(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

CVPTXMD3M, CV or **cv_ptx_MD3M** – specific isochoric heat capacity c_v in kJ/(kg K)

Range of validity

Temperature range:	from t = 0°C to 400°C
Pressure range:	from p = 0.0000048971 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 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.

Saturated liquid and	Temperature ranges from $t = 0°C$ to $t_c = 355.21°C$
saturated vapor line:	Pressure ranges from $p_s(0°C) = 0.0000048971$ bar to $p_c = 9.45229$ bar

Results for wrong input values

Result **CVPTXMD3M = -1000**, **CV = -1000** or **cv_ptx_MD3M = -1000** for input values:

Single phase region: (x = -1)	p > 300 bar or p < 0.0000048971 bar or t > 400 °C or t < 0°C
Saturation lines:	at $p = -1000$ and $t > t_c = 355.21°C$ to $t < 0°C$ at $t = -1000$ and $p > p_c = 9.451229$ bar or $p < p_s(0°C) = 0.0000048971$ bar or or $p > p_c = 9.45229$ bar or $p < p_s(0°C) = 0.0000048971$ bar and $t > t_c = 355.21°C$ or $t < 0°C$

References: [1], [2]

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_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION DPDTVPTXMD3M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_DPDTVPTXMD3M(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

DPDTVPTXMD3M, **DPDTV** or **dpdtv_ptx_MD3M** - Derivative of pressure with respect to temperature (at constant specific volume) dpdtv in kPa/K

Range of validity

Temperature range: from t = 0°C to 400°C
Pressure range: from p = 0.0000048971 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 $t = 0°C$ to $t_c = 355.21°C$
Pressure ranges from $p_s(0°C) = 0.0000048971$ bar to $p_c = 9.45229$ bar

Results for wrong input values

Result **DPDTVPTXMD3M = -1000**, **DPDTV = -1000** or **dpdtvo_ptx_MD3M = -1000** for input values:

Single phase region: (x = -1)
p > 300 bar or p < 0.0000048971 bar or
t > 400 °C or t < 0°C

Boiling or dew curve:
at $p = -1000$ and $t > t_c = 355.21°C$ to $t < 0°C$
at $t = -1000$ and $p > p_c = 9.451229$ bar
or $p < p_s(0°C) = 0.0000048971$ bar or
or $p > p_c = 9.45229$ bar or $p < p_s(0°C) = 0.0000048971$ bar and
$t > t_c = 355.21°C$ or $t < 0°C$

References: [1], [2]

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_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION DPDVTPTXMD3M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_DPDVTPTXMD3M(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

DPDVTPTXMD3M, **DPDVT** or **dpdvt_ptx_MD3M** - Derivative of pressure with respect to temperature (at constant specific volume) dpdvt in kPa/K

Range of validity

Temperature range: from t = 0°C to 400°C
Pressure range: from p = 0.0000048971 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 $t = 0°\text{C}$ to $t_c = 355.21°\text{C}$
Pressure ranges from $p_s(0°\text{C}) = 0.0000048971\,\text{bar}$ to $p_c = 9.45229\,\text{bar}$

Results for wrong input values

Result **DPDVTPTXMD3M = -1000**, **DPDVT = -1000** or **dpdvt_ptx_MD3M = -1000** for input values:

Single phase region: (x = -1)
p > 300 bar or p < 0.0000048971 bar or
t > 400 °C or t < 0°C

Boiling or dew curve:
at $p = -1000$ and $t > t_c = 355.21°\text{C}$ to $t < 0°\text{C}$
at $t = -1000$ and $p > p_c = 9.451229\,\text{bar}$
or $p < p_s(0°\text{C}) = 0.0000048971\,\text{bar}$ or
or $p > p_c = 9.45229$ bar or $p < p_s(0°\text{C}) = 0.0000048971$ bar and
$t > t_c = 355.21°\text{C}$ or $t < 0°\text{C}$

References: [1], [2]

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

Function Name:	**h_ptx_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION HPTXMD3M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_HPTXMD3M(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

HPTXMD3M, **H** or **h_ptx_MD3M** - Specific enthalpy *h* in kJ/kg

Range of validity

Temperature range: from t = 0°C to 400°C
Pressure range: from p = 0.0000048971 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 $t = 0°\mathrm{C}$ to $t_c = 355.21°\mathrm{C}$
Pressure ranges from $p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ to $p_c = 9.45229\,\mathrm{bar}$

Results for wrong input values

Result **HPTXMD3M = -1000**, **H = -1000** or **h_ptx_MD3M = -1000** for input values:

Single phase region: (x = -1)
p > 300 bar or p < 0.0000048971 bar or
t > 400 °C or t < 0°C

Wet steam region:
at $p = -1000$ and $t > t_c = 355.21°\mathrm{C}$ to $t < 0°\mathrm{C}$
at $t = -1000$ and $p > p_c = 9.451229\,\mathrm{bar}$
or $p < p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ or
or $p > p_c = 9.45229$ bar or $p < p_s(0°\mathrm{C}) = 0.0000048971$ bar and
$t > t_c = 355.21°\mathrm{C}$ or $t < 0°\mathrm{C}$

References: [1], [2]

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

Function Name:	**kappa_ptx_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION KAPPAPTXMD3M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_KAPPAPTXMD3M(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

KAPPAPTXMD3M, **KAPPA** or **kappa_ptx_MD3M** – Isentropic exponent $\kappa = \dfrac{w^2}{p \cdot v}$

Range of validity

Temperature range: from t = 0°C to 400°C
Pressure range: from p = 0.0000048971 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 $t = 0°\mathrm{C}$ to $t_c = 355.21°\mathrm{C}$ Pressure ranges from $p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ to $p_c = 9.45229\,\mathrm{bar}$

Results for wrong input values

Result **KAPPAPTXMD3M**, **KAPPA = -1000** or **kappa_ptx_MD3M = -1000** for input values:

Single phase region: (x = -1)	p > 300 bar or p < 0.0000048971 bar or t > 400 °C or t < 0°C
Boiling or dew curve:	at $p = -1000$ and $t > t_c = 355.21°\mathrm{C}$ to $t < 0°\mathrm{C}$ at $t = -1000$ and $p > p_c = 9.451229\,\mathrm{bar}$ or $p < p_s(0°\mathrm{C}) = 0.0000048971$ bar or or $p > p_c = 9.45229$ bar or $p < p_s(0°\mathrm{C}) = 0.0000048971$ bar and $t > t_c = 355.21°\mathrm{C}$ or $t < 0°\mathrm{C}$

References: [1], [2]

Vapor Pressure p_s = f(t)

Function Name:	**ps_t_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION PSTMD3M(T)** REAL*8 T
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_PSTMD3M(PS,T)** REAL*8 PS,T

Input Values:

T - Temperature t in °C

Result

PSTMD3M, **ps** or **ps_t_MD3M** – Vapor pressure p_s in bar

Range of validity

Temperature ranges from $t = 0°C$ to $t_c = 355.21°C$

Results for wrong input values

Result **PSTMD3M = -1000**, **PS = -1000** or **ps_t_MD3M = -1000** for input values:

$t < 0°C$ or $t > t_c = 355.21°C$

References: [1], [2]

Density ρ = f(p,t,x)

Function Name:	**rho_ptx_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION RHOPTXMD3M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_RHOPTXMD3M(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

RHOPTXMD3M, **RHO** or **rho_ptx_MD3M** – Density ρ in kg/ m^3

Range of validity

Temperature range: from t = 0°C to 400°C
Pressure range: from p = 0.0000048971 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 $t = 0°\text{C}$ to $t_c = 355.21°\text{C}$
Pressure ranges from $p_s(0°\text{C}) = 0.0000048971\,\text{bar}$ to $p_c = 9.45229\,\text{bar}$

Results for wrong input values

Result **RHOPTXMD3M = -1000**, **RHO = -1000** or **rho_ptx_MD3M = -1000** for input values:

Single phase region: (x = -1)
p > 300 bar or p < 0.0000048971 bar or
t > 400 °C or t < 0°C

Wet steam region:
at $p = -1000$ and $t > t_c = 355.21°\text{C}$ to $t < 0°\text{C}$
at $t = -1000$ and $p > p_c = 9.451229\,\text{bar}$
or $p < p_s(0°\text{C}) = 0.0000048971$ bar or
or $p > p_c = 9.45229$ bar or $p < p_s(0°\text{C}) = 0.0000048971$ bar and
$t > t_c = 355.21°\text{C}$ or $t < 0°\text{C}$

References: [1], [2]

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

Function Name:	**s_ptx_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION SPTXMD3M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_SPTXMD3M(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

SPTXMD3M, **S** or **s_ptx_MD3M** - Specific entropy *s* in kJ/kg K

Range of validity

Temperature range: from t = 0°C to 400°C
Pressure range: from p = 0.0000048971 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 $t = 0°\mathrm{C}$ to $t_c = 355.21°\mathrm{C}$
Pressure ranges from $p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ to $p_c = 9.45229\,\mathrm{bar}$

Results for wrong input values

Result **SPTXMD3M = -1000**, **S = -1000** or **s_ptx_MD3M = -1000** for input values:

Single phase region: (x = -1)
p > 300 bar or p < 0.0000048971 bar or
t > 400 °C or t < 0°C

Wet steam region:
at $p = -1000$ and $t > t_c = 355.21°\mathrm{C}$ to $t < 0°\mathrm{C}$
at $t = -1000$ and $p > p_c = 9.451229\,\mathrm{bar}$
or $p < p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ or
or $p > p_c = 9.45229\,\mathrm{bar}$ or $p < p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ and
$t > t_c = 355.21°\mathrm{C}$ or $t < 0°\mathrm{C}$

References: [1], [2]

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

Function Name:	**t_ph_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION TPHMD3M(P,H)** REAL*8 P,H
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_TPHMD3M(T,P,H)** REAL*8 T,P,H

Input Values:

P - Pressure *p* in bar

H - Specific enthalpy *h* in kJ/kg

Result

TPHMD3M, **T** or **t_ph_MD3M -** Temperature *t* in °C

Range of validity

Temperature range: from t = 0°C to 400°C
Pressure range: from p = 0.0000048971 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 $p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ to $p_c = 9.45229\,\mathrm{bar}$

Results for wrong input values

Result **T_PH_MD3M**, **T = -1000** or **t_ph_MD3M = -1000** for input values:

Single phase region: (x = -1)	p > 300 bar or p < 0.0000048971 bar or at result t > 400 °C or t < 0°C
Boiling or dew curve:	or $p > p_c = 9.45229$ bar or $p < p_s(0°\mathrm{C}) = 0.0000048971$ bar and at result $t > t_c = 355.21°\mathrm{C}$ or $t < 0°\mathrm{C}$

References: [1], [2]

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

Function Name:	**t_ps_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION TPSMD3M(P,S)** REAL*8 P,S
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_TPSMD3M(T,P,S)** REAL*8 T,P,S

Input Values:

P - Pressure *p* in bar

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

Result

TPSMD3M, **T** or **t_ps_MD3M -** Temperature *t* in °C

Range of validity

Temperature range: from t = 0°C to 400°C
Pressure range: from p = 0.0000048971 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 $p_s(0°\,C) = 0.0000048971\,\text{bar}$ to $p_c = 9.45229\,\text{bar}$

Results for wrong input values

Result **T_PS_MD3M**, **T = -1000** or **t_ps_MD3M = -1000** for input values:

Single phase region: (x = -1)
p > 300 bar or p < 0.0000048971 bar or
at result t > 400 °C or t < 0°C

Boiling or dew curve:
or $p > p_c = 9.45229$ bar or $p < p_s(0°C) = 0.0000048971$ bar and
at result $t > t_c = 326.25°C$ or $t < 0°C$

References: [1], [2]

Saturation Temperature t_s = f(p)

Function Name:	**ts_p_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION TSPMD3M(P)** REAL*8 P
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_TSPMD3M(TS,P)** REAL*8 TS,P

Input Values:

P - Pressure p in bar

Result

TSPMD3M, **TS** or **ts_p_MD3M** – Saturation Temperature t_s in °C

Range of validity

Pressure ranges from $p_s(0°C) = 0.0000048971$ bar to $p_c = 9.45229$ bar

Results for wrong input values

Result **TSPMD3M = -1000**, **TS = -1000** or **ts_p_MD3M = -1000** for input values:

$p > p_c = 9.45229$ bar or $p < p_s(0°C) = 0.0000048971$ bar

References: [1], [2]

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

Function Name:	**u_ptx_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION UPTXMD3M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_UPTXMD3M(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

UPTXMD3M, **U** or **u_ptx_MD3M** - Specific internal energy *u* in kJ/kg

Range of validity

Temperature range: from t = 0°C to 400°C
Pressure range: from p = 0.0000048971 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* <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. 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 $t = 0°\mathrm{C}$ to $t_c = 355.21°\mathrm{C}$
Pressure ranges from $p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ to $p_c = 9.45229\,\mathrm{bar}$

Results for wrong input values

Result **UPTXMD3M = -1000**, **U = -1000** or **u_ptx_MD3M = -1000** for input values:

Single phase region: (x = -1)
p > 300 bar or p < 0.0000048971 bar or
t > 400 °C or t < 0°C

Wet steam region:
at $p = -1000$ and $t > t_c = 355.21°\mathrm{C}$ to $t < 0°\mathrm{C}$
at $t = -1000$ and $p > p_c = 9.451229\,\mathrm{bar}$
or $p < p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ or
or $p > p_c = 9.45229$ bar or $p < p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ and
$t > t_c = 355.21°\mathrm{C}$ or $t < 0°\mathrm{C}$

References: [1], [2]

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

Function Name:	**v_ptx_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION VPTXMD3M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_VPTXMD3M(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

VPTXMD2M, **V** or **v_ptx_MD2M** – Specific volume *v* in m^3/kg

Range of validity

Temperature range: from *t* = 0°C to 400°C
Pressure range: from *p* = 0.0000048971 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* <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. 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 $t = 0°C$ to $t_c = 355.21°C$
Pressure ranges from $p_s(0°C) = 0.0000048971$ bar to $p_c = 9.45229$ bar

Results for wrong input values

Result **VPTXMD3M = -1000**, **V = -1000** or **v_ptx_MD3M = -1000** for input values:

Single phase region: (x = -1)
p > 300 bar or *p* < 0.0000048971 bar or
t > 400 °C or *t* < 0°C

Wet steam region:
at $p = -1000$ and $t > t_c = 355.21°C$ to $t < 0°C$
at $t = -1000$ and $p > p_c = 9.451229$ bar
or $p < p_s(0°C) = 0.0000048971$ bar or
or $p > p_c = 9.45229$ bar or $p < p_s(0°C) = 0.0000048971$ bar and
$t > t_c = 355.21°C$ or $t < 0°C$

References: [1], [2]

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

Function Name:	**w_ptx_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION WPTXMD3M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_WPTXMD3M(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

WPTXMD3M, **W** or **w_ptx_MD3M -** Speed of sound *w* in m/s

Range of validity

Temperature range: from t = 0°C to 400°C
Pressure range: from p = 0.0000048971 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 $t = 0°\mathrm{C}$ to $t_c = 355.21°\mathrm{C}$
Pressure ranges from $p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ to $p_c = 9.45229\,\mathrm{bar}$

Results for wrong input values

Result **WPTXMD3M = -1000, W = -1000** or **w_ptx_MD3M = -1000** for input values:

Single phase region: (x = -1)
p > 300 bar or p < 0.0000048971 bar or
t > 400 °C or t < 0°C

Boiling or dew curve:
at $p = -1000$ and $t > t_c = 355.21°\mathrm{C}$ to $t < 0°\mathrm{C}$
at $t = -1000$ and $p > p_c = 9.451229\,\mathrm{bar}$
or $p < p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ or
or $p > p_c = 9.45229\,\mathrm{bar}$ or $p < p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ and
$t > t_c = 355.21°\mathrm{C}$ or $t < 0°\mathrm{C}$

References: [1], [2]

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

Function Name:	**x_ph_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION XPHMD3M(P,H)** REAL*8 P,H
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_XPHMD3M(X,P,H)** REAL*8 X,P,H

Input Values:

P - Pressure *p* in bar

H - Specific enthalpy *h* in kJ/kg

Result

XPHMD3M, **X** or **x_ph_MD3M -** Vapor fraction *x* in (kg saturated steam/kg wet steam)

Range of validity

Temperature range: from t = 0°C to 400°C
Pressure range: from p = 0.0000048971 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. In case of wet steam, *x* will be calculated, otherwise the result is set to x = -1.

Wet steam region: Pressure ranges from $p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ to $p_c = 9.45229\,\mathrm{bar}$

Results for wrong input values

Result **X_PH_MD3M**, **X =** -1 or **x_ph_MD3M =** -1 for input values:

If the state point is located in the single phase region:
$p > p_c = 9.45229$ bar or $p < p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$

References: [1], [2]

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

Function Name:	**x_ps_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION XPSMD3M(P,S)** REAL*8 P,S
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_XPSMD3M(X,P,S)** REAL*8 X,P,S

Input Values:

P - Pressure *p* in bar

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

Result

XPSMD3M, **X** or **x_ps_MD3M -** Vapor fraction *x* in (kg saturated steam/kg wet steam)

Range of validity

Temperature range: from t = 0°C to 400°C
Pressure range: from p = 0.0000048971 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. In case of wet steam, *x* will be calculated, otherwise the result is set to x = -1.

Wet steam region: Pressure ranges from $p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ to $p_c = 9.45229\,\mathrm{bar}$

Results for wrong input values

Result **X_PS_MD3M**, **X = -1** or **x_ps_MD3M = -1** for input values:

If the state point is located in the single phase region:
$p > p_c = 9.45229$ bar or $p < p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$

References: [1], [2]

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

Function Name:	**Z_ptx_MD3M**
Subroutine with function value: for call from Fortran	**REAL*8 FUNCTION ZPTXMD3M(P,T,X)** REAL*8 P,T,X
Subroutine with parameter: for call from DLL	**INTEGER*4 FUNCTION C_ZPTXMD3M(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

ZPTXMD3M, **Z** or **Z_ptx_MD3M -** Compression Factor

Range of validity

Temperature range: from t = 0°C to 400°C
Pressure range: from p = 0.0000048971 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 $t = 0°\mathrm{C}$ to $t_c = 355.21°\mathrm{C}$

Pressure ranges from $p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ to $p_c = 9.45229\,\mathrm{bar}$

Results for wrong input values

Result **ZPTXMD3M = -1000, Z = -1000** or **Z_ptx_MD3M = -1000** for input values:

Single phase region: (x = -1)
p > 300 bar or p < 0.0000048971 bar or
t > 400 °C or t < 0°C

Boiling or dew curve:
at $p = -1000$ and $t > t_c = 355.21°\mathrm{C}$ to $t < 0°\mathrm{C}$
at $t = -1000$ and $p > p_c = 9.451229\,\mathrm{bar}$
or $p < p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ or
or $p > p_c = 9.45229\,\mathrm{bar}$ or $p < p_s(0°\mathrm{C}) = 0.0000048971\,\mathrm{bar}$ and
$t > t_c = 355.21°\mathrm{C}$ or $t < 0°\mathrm{C}$

References: [1], [2]

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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)

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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.

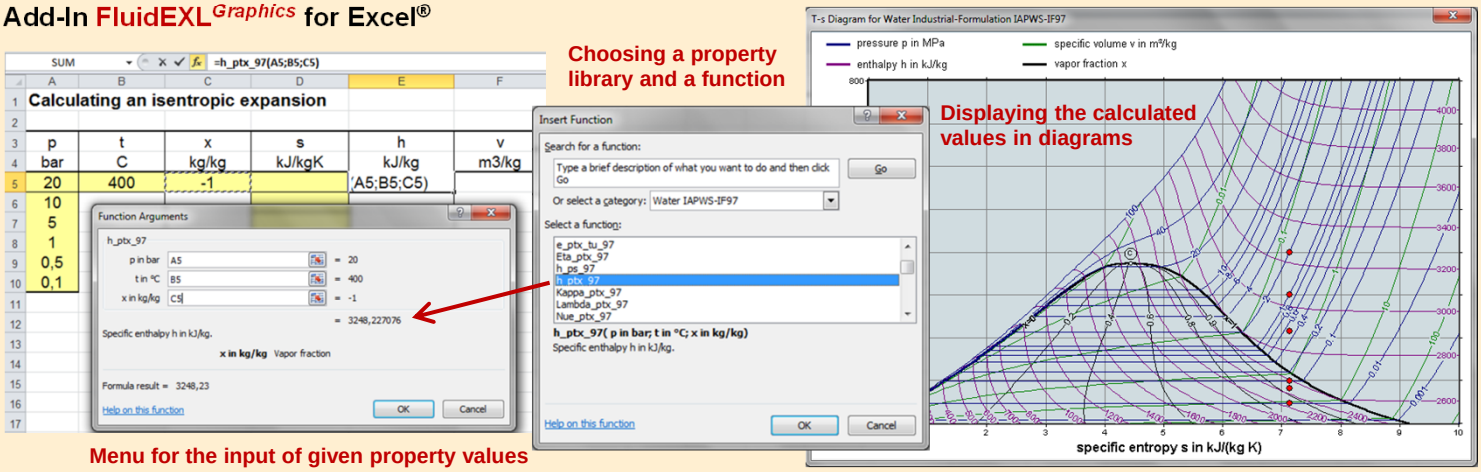
[a] Not all of these property functions are available in all property libraries.

www.thermodynamic-property-libraries.com

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

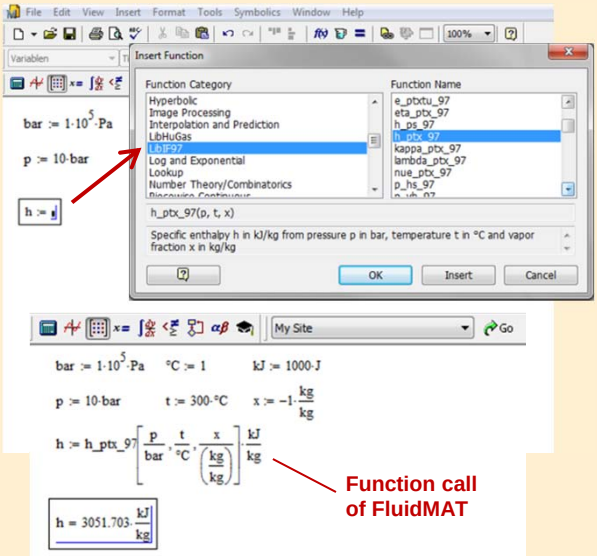
Property Software for Calculating Heat Cycles, Boilers, Turbines, and Refrigerators

Add-In FluidEXL*Graphics* for Excel®



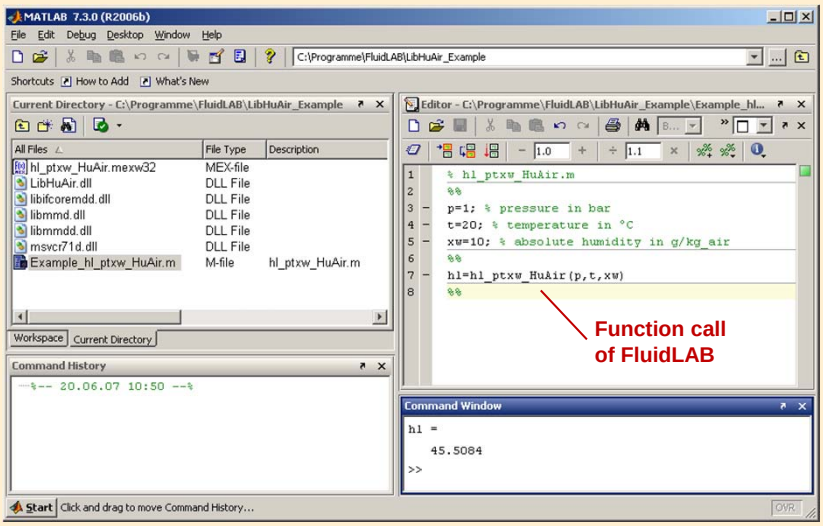
Add-In FluidMAT for Mathcad®

The property libraries can be used in Mathcad®.



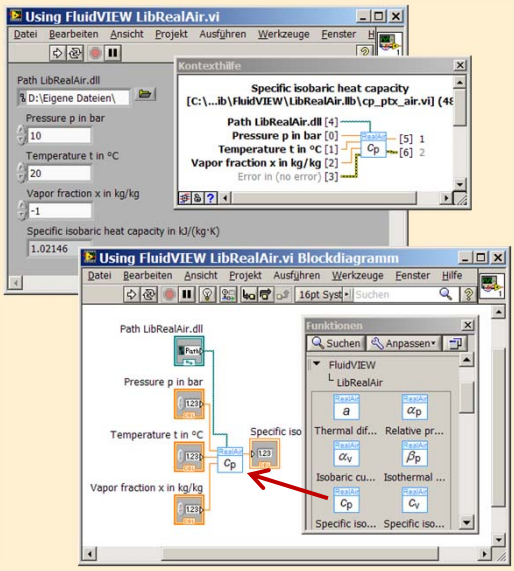
Add-In FluidLAB for MATLAB®

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



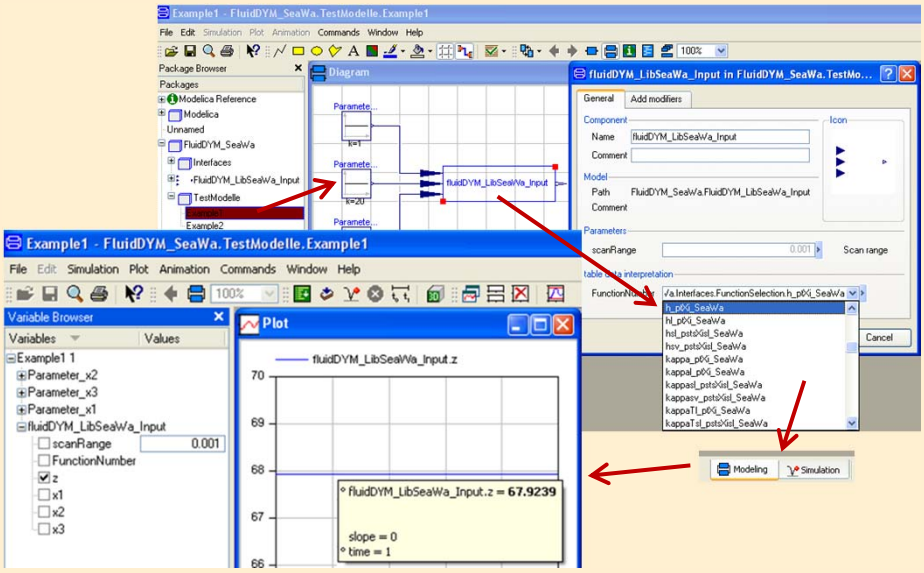
Add-On FluidVIEW for LabVIEW®

The property functions can be calculated in LabVIEW®.

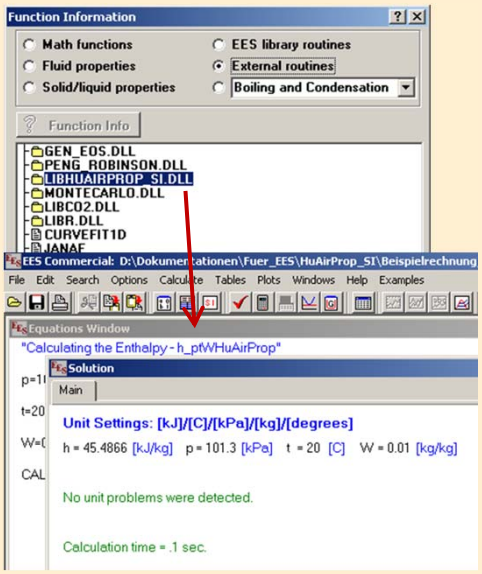


Add-In FluidDYM for DYMOLA® (Modelica) and SimulationX®

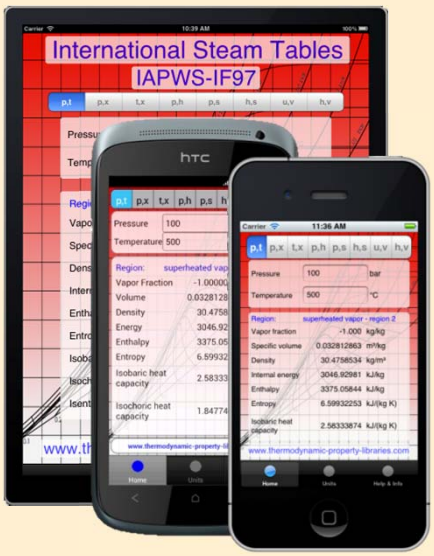
The property functions can be called in DYMOLA® and SimulationX®



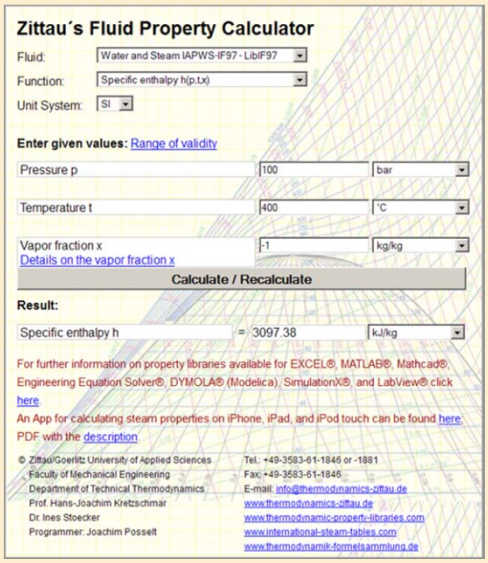
Add-In FluidEES for Engineering Equation Solver®



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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Department of Technical Thermodynamics
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Dr. Ines Stoecker
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02763 Zittau, Germany

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Internet: www.thermodynamics-zittau.de
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

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- 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
Multiparameter equations of state for selected siloxanes
Fluid Phase Equilibria, 263, (2008) S. 115-130

[2] Span, R.
Multiparameter Equations of State;
An Accurate Source of Thermodynamic Property Data
Springer Verlag 2000

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
Weihenstephan University of Applied Sciences	07/2011, 09/2011, 10/2011
Forschungszentrum Juelich	07/2011
RWTH Aachen University	07/2011, 08/2011
Voith, Zschopau	07/2011
INNEO Solutions, Ellwangen	06/2011
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Technical University of Freiberg	06/2011
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2010

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MAN Turbo Machines, Oberhausen	09/2004
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2003

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Technip Benelux BV, Zoetermeer, Netherlands	01/2003
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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
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SAAS, Possendorf/Dresden	02/2002
Siemens, Karlsruhe (general license for the WinIS information system)	02/2002
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Eco Design, Saitamaken, Japan	01/2001
M&M Turbine Technology, Bielefeld	01/2001, 09/2001
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