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Property Library for the Industrial Formulation IAPWS-IF97 for Water und Steam

FluidLAB
LibIF97

for MATLAB®
Student's Version

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Software for the Industrial Formulation IAPWS-IF97 of Water and Steam Including DLL and Add-In for MATLAB®

FluidLAB
LibIF97
Student's Version

Contents

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0 Package Contents

0.1 Zip file for 32-bit MATLAB®

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

"CD_FluidLAB_LibIF97_Stud.zip"

Water and Steam calculated from the Industrial Formulation IAPWS-IF97

Including the following files:

FluidLAB_LibIF97_Stud_Setup.exe	- Installation program for the FluidLAB Add-On for use in MATLAB®
FluidLAB_LibIF97_Stud_Docu_Eng.pdf	- User's Guide

0.2 Zip file for 64-bit MATLAB®

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

"CD_FluidLAB_LibIF97_Stud_64.zip"

Water and Steam calculated from the Industrial Formulation IAPWS-IF97

Including the following files and folders:

Files:

Setup.exe	- Self-extracting and self-installing program for FluidLAB
FluidLAB_LibIF97_Stud_64.msi	- Installation program for the FluidLAB Add-On for use in MATLAB®
FluidLAB_LibIF97_Stud_Docu_Eng.pdf	- User's Guide

Folders:

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

1. Range of Validity and Program Library Structure

The International Association for the Properties of Water and Steam (IAPWS) issued the IAPWS-IF97 Industrial Formulation for Thermodynamic Properties of Water and Steam in 1997. This standard must be applied worldwide in final warranty calculations for power plants which use water and steam as working fluid.

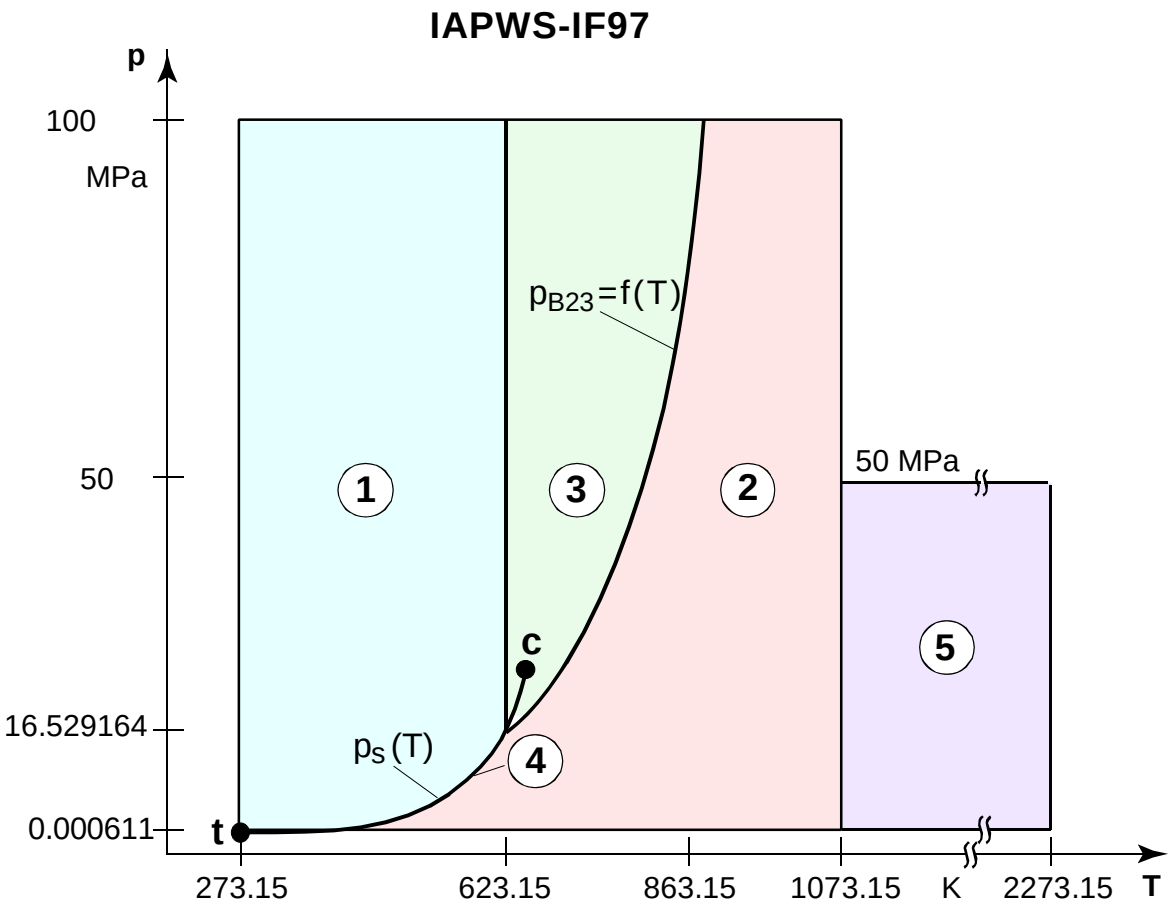
Figure 1 shows the range of validity of the equation set of the Industrial Formulation, fully named

"IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam",

abbreviated

"IAPWS-IF97".

The IAPWS-IF97 range of state includes temperatures from 273.15 K up to 1073.13 K at pressures from 0.000611 MPa to 100 MPa and up to 2273.15 K at pressures up to 50 MPa. Internally, the entire range of validity is divided into five calculation regions (see figure below). The fundamental equations of these regions are described in detail in the official IAPWS release [1], [2], and [3].



The students' version of the LibIF97 program library is valid for the regions 1 and 2, and for the wet steam region (region 4).

2. Property Functions of the Library

Functional Dependence	Function Name	Property or Function	Unit of the Function Value
$c_p = f(p,T,x)$	cp_pTx_97	Specific isobaric heat capacity	kJ/kg · K
$\eta = f(p,T,x)$	eta_pTx_97	Dynamic viscosity	Pa · s = kg/m · s
$h = f(p,T,x)$	h_pTx_97	Specific enthalpy	kJ/kg
$\lambda = f(p,T,x)$	lambda_pTx_97	Thermal conductivity	W/m K
$p_s = f(T)$	ps_T_97	Saturation pressure from temperature	MPa
$s = f(p,T,x)$	s_pTx_97	Specific entropy	kJ/kg · K
$T = f(p,h)$	T_ph_97	Backward function: temperature from pressure and specific enthalpy	K
$T = f(p,s)$	T_ps_97	Backward function: temperature from pressure and specific entropy	K
$T_s = f(p)$	Ts_p_97	Saturation temperature from pressure	K
$v = f(p,T,x)$	v_pTx_97	Specific volume	m^3/kg
$x = f(p,h)$	x_ph_97	Backward function: vapor fraction from pressure and specific enthalpy	kg/kg
$x = f(p,s)$	x_ps_97	Backward function: vapor fraction from pressure and specific entropy	kg/kg

Units:

T in K
p in MPa
x in (kg saturated steam)/(kg wet steam)

The IAPWS-IF97 range of validity (regions 1, 2, 4, see Figure 1)

Temperature range: from 273.15 K to 1073.15 K

Pressure range: from 0.000611 MPa to 100 MPa

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 = -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 this is not the case the calculation for the property of the chosen function results in –1.

Wet steam region of the IAPWS-IF97: Temperature ranges from T = 273.15 K to T = 623.15 K
Pressure ranges from p = 0.000611 MPa to p = 16.529 MPa

Note.

If the calculated value results in –1 (except for *x*), the values entered represent a state point beyond the range of validity of IAPWS-IF97. For further information on each function and its range of validity see Chapter 4. The same information may also be accessed via the online help pages.

3 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 water and steam from the LibIF97_Stud property library.

3.1 Installing FluidLAB including LibIF97_Stud

Installing FluidLAB including LibIF97_Stud for 32-bit MATLAB®

This section describes the installation of FluidLAB LibIF97_Stud for a 32-bit version of MATLAB®. Before you begin, it is best to close any Windows® applications, since Windows® may need to be rebooted during the installation process.

After you have downloaded and extracted the zip-file "CD_FluidLAB_LibIF97_Stud.zip", you will see the folder

CD_FluidLAB_LibIF97_Stud

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

Open this folder by double-clicking on it.

In this folder you will see the following files:

FluidLAB_LibIF97_Stud_Docu_Eng.pdf
FluidLAB_LibIF97_Stud_Setup.exe

In order to run the installation of FluidLAB including the LibIF97_Stud property library, double-click on the file

FluidLAB_LibIF97_Stud_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\LibIF97_Stud	(for English version of Windows)
C:\Programme\FluidLAB\LibIF97_Stud	(for German version of Windows)

By clicking the "Browse…" button, you can change the installation directory before installation (see Figure 3.1).

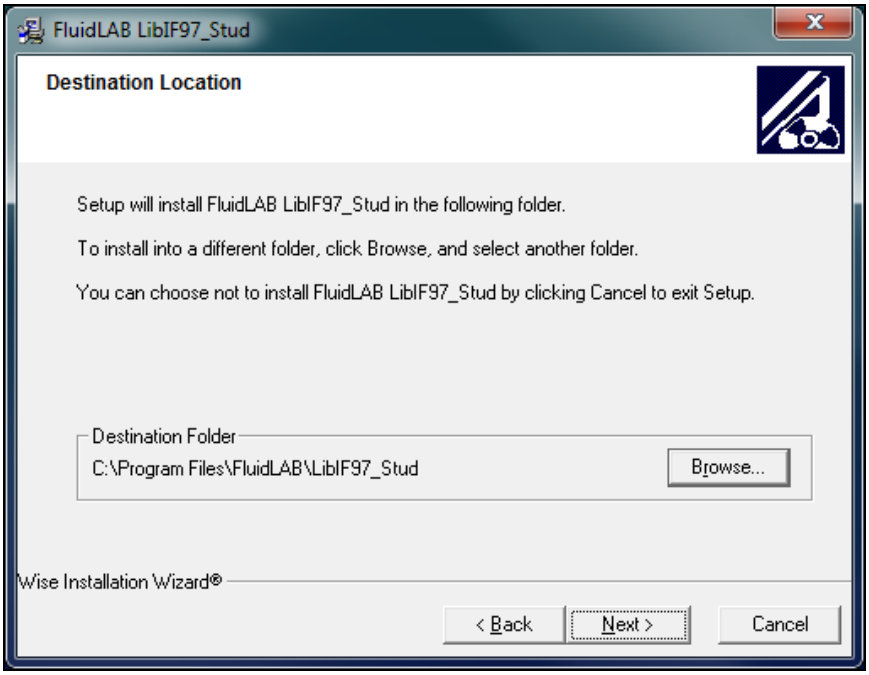


Figure 3.1: "Destination Location"

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

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

The installation program has copied the following files for LibIF97_Stud into the directory

"C:\Program Files\FluidLAB\LibIF97_Stud" (for English version of Windows)

"C:\Programme\FluidLAB\LibIF97_Stud" (for German version of Windows):

Dformd.dll	LibIF97_Stud.dll
Dforrt.dll	Unwise.exe
INSTALL.LOG	Unwise.ini

Installing FluidLAB including LibIF97_Stud for 64-bit MATLAB®

This section describes the installation of FluidLAB LibIF97_Stud.

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_LibIF97_Stud_64.zip", you will see the folder

CD_FluidLAB_LibIF97_Stud

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

Open this folder by double-clicking on it.

In this folder you will see the following two files:

FluidLAB_LibIF97_Stud_Docu_Eng.pdf
FluidLAB_LibIF97_Stud_64.msi
Setup.exe

and folders:

vcredist_x64
WindowsInstaller3_1.

In order to run the installation of FluidLAB including, the LibIF97_Stud property library, double-click on the file

Setup.exe.

Installation of FluidLAB LibIF97_Stud starts with a window noting that the installer will guide you through the installation process. Click the "Next >" button to continue.

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

C:\Program Files\FluidLAB\LibIF97_Stud (for English version of Windows)
C:\Programme\FluidLAB\LibIF97_Stud (for German version of Windows):

By clicking the "Browse…" button, you can change the installation directory before installation (see Figure 3.2).

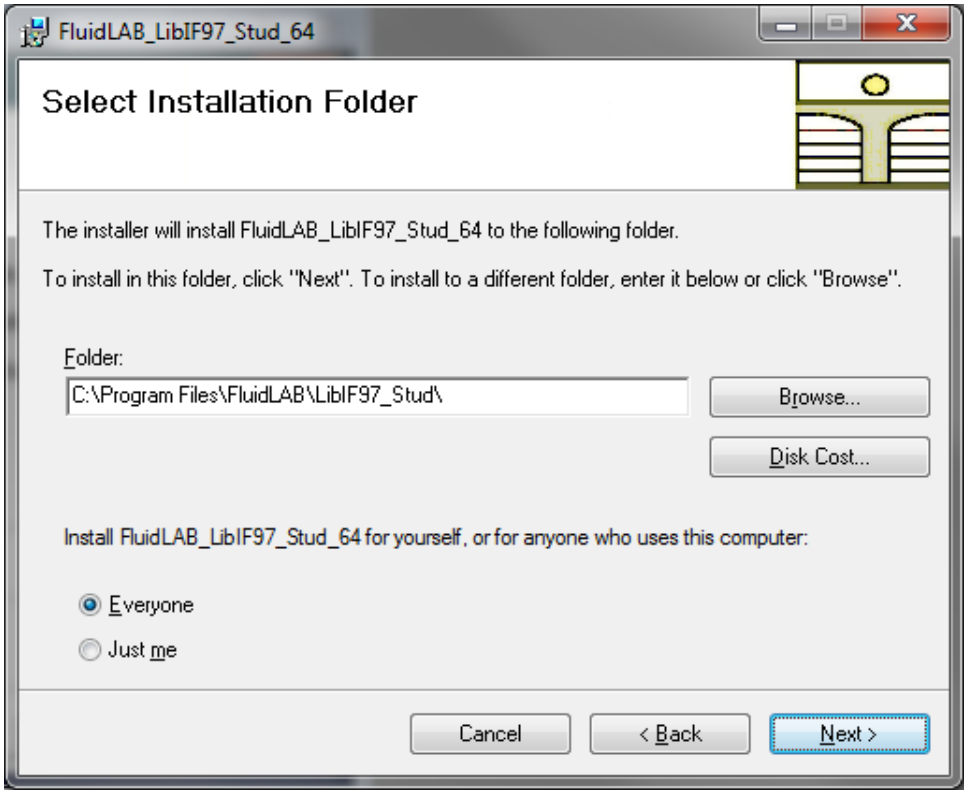


Figure 3.2: "Select Installation Folder"

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

After FluidLAB has been installed, you will see the sentence "FluidLAB_LibIF97_Stud_64 has been successfully installed." Confirm this by clicking the "Close" button.

The installation program has copied the following files for LibIF97_Stud into the directory

"C:\Program Files\FluidLAB\LibIF97_Stud" (for English version of Windows)
"C:\Programme\FluidLAB\LibIF97_Stud" (for German version of Windows):

capt_ico_big.ico	libifcoremd.dll
LibIF97_Stud.dll	libmmd.dll

The installation programs for both the 32-bit and the 64-bit Windows version have copied the following function files for LibIF97_Stud into the directory

"C:\Program Files\FluidLAB\LibIF97_Stud" (for English version of Windows)
"C:\Programme\FluidLAB\LibIF97_Stud" (for German version of Windows):

- MATLAB®-Interface-Program for calculable functions

cp_pTx_97	T_ph_97
eta_pTx_97	T_ps_97
h_pTx_97	Ts_p_97
lambda_pTx_97	v_pTx_97
ps_T_97	x_ph_97
s_pTx_97	x_ps_97

Please note that there is a <u>difference in the file extension</u> of the function files.

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

.mexw32

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

.mexw64

into your LibIF97_Stud directory (the standard being

C:\Program Files\FluidLAB\LibIF97_Stud (for English version of Windows)
C:\Programme\FluidLAB\LibIF97_Stud (for German version of Windows)).

3.2 Example: Calculation of $h = f(p,T,x)$ in an M-File

Now we will calculate, step by step, the specific enthalpy h as a function of pressure p, temperature T and vapor fraction x, 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 "\LibIF97_Stud"; it is generally saved under:

  "C:\Program Files\FluidLAB" (for English version of Windows)
  "C:\Programme\FluidLAB" (for German version of Windows)
- Create the folder "\LibIF97_Stud_Example" by clicking on "File" in the Explorer® menu, then "New" in the menu which appears and afterwards selecting "Folder". Name the new folder "\LibIF97_Stud_Example."
- You will now see the following window:

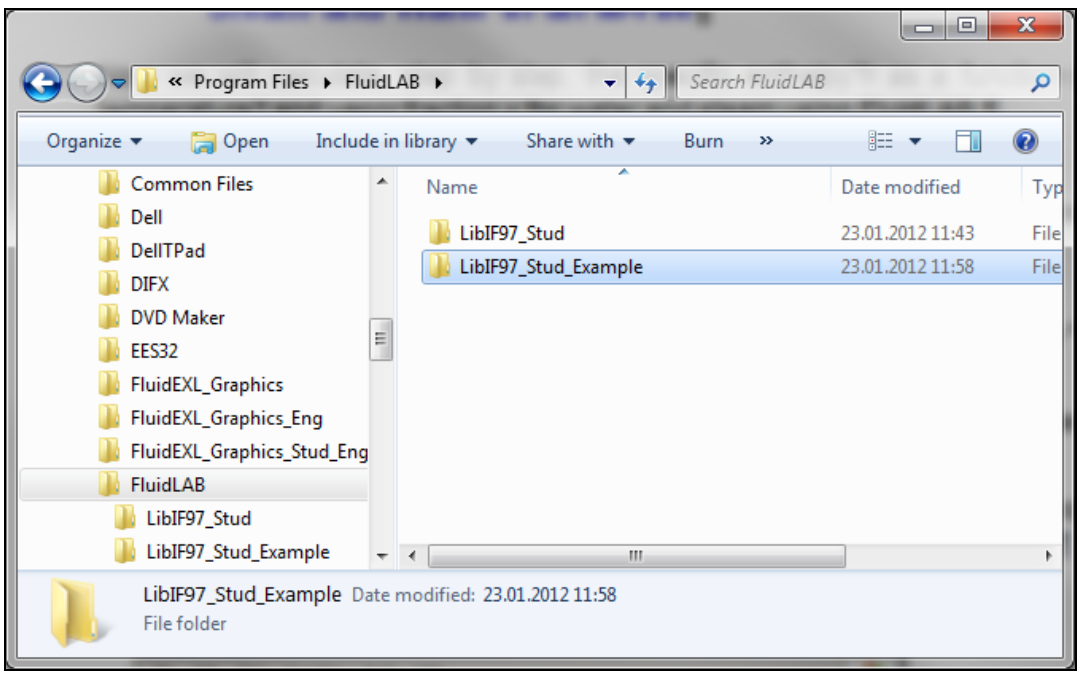


Figure 3.3: Folders "LibIF97_Stud" and "LibIF97_Stud_Example"

- Switch into the directory "\LibIF97_Stud" within "\FluidLAB", the standard being

  "C:\Program Files\FluidLAB\LibIF97_Stud" (for English version of Windows)
  "C:\Programme\FluidLAB\LibIF97_Stud" (for German version of Windows).

- You will see the following window:

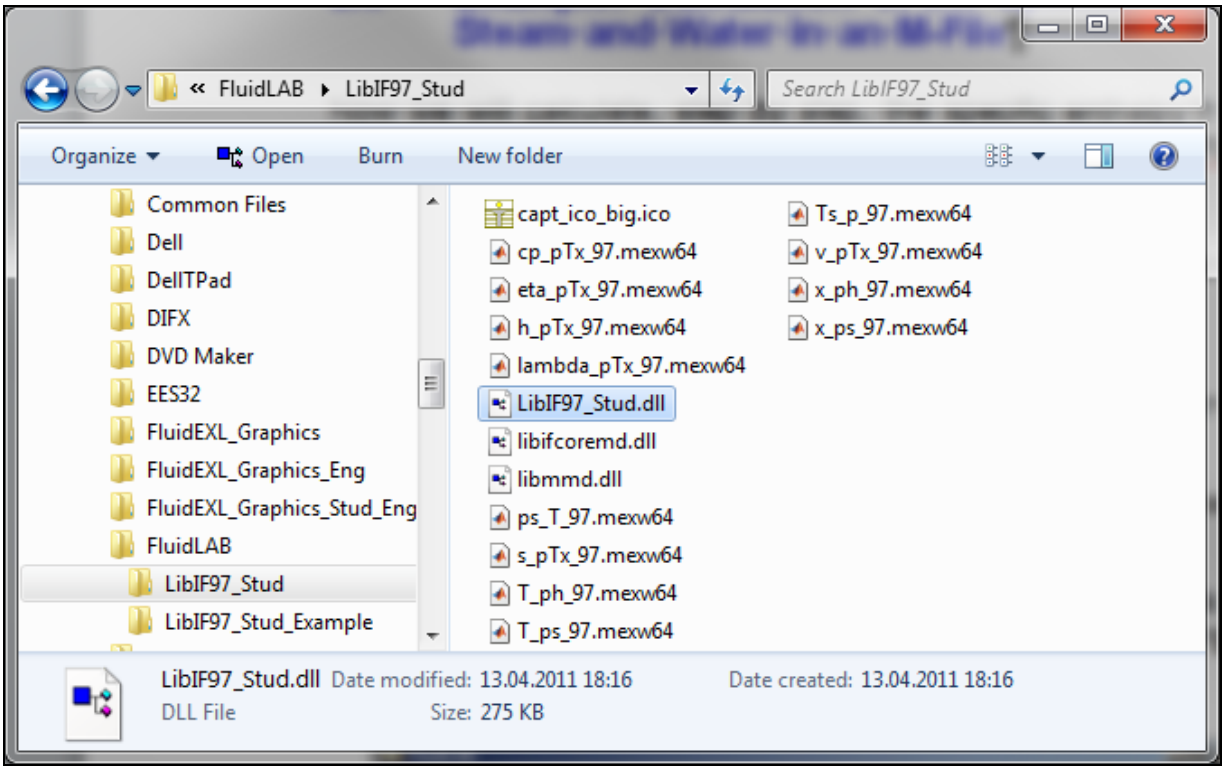


Figure 3.4: Contents of the folder "LibIF97_Stud"

If you have installed the 32-bit version of LibIF97_Stud you will now have to copy the following files into the directory "C:\Program Files\FluidLAB\LibIF97_Stud_Example" in order to calculate the function $h = f(p,T,x)$.

- The following files are needed:
  - "h_pTx_97.mexw32"
  - "LibIF97_Stud.dll"
  - "Dformd.dll"
  - "Dforrt.dll.dll"
- Click the file "h_pTx_IF97.mexw32", then click "Edit" in the upper menu bar and select "Copy".
- Switch into the directory "C:\Program Files\FluidLAB\LibIF97_Stud_Example ", click "Edit" and select "Paste".
- Repeat these steps in order to copy the other files listed above.
- You will see the following window:

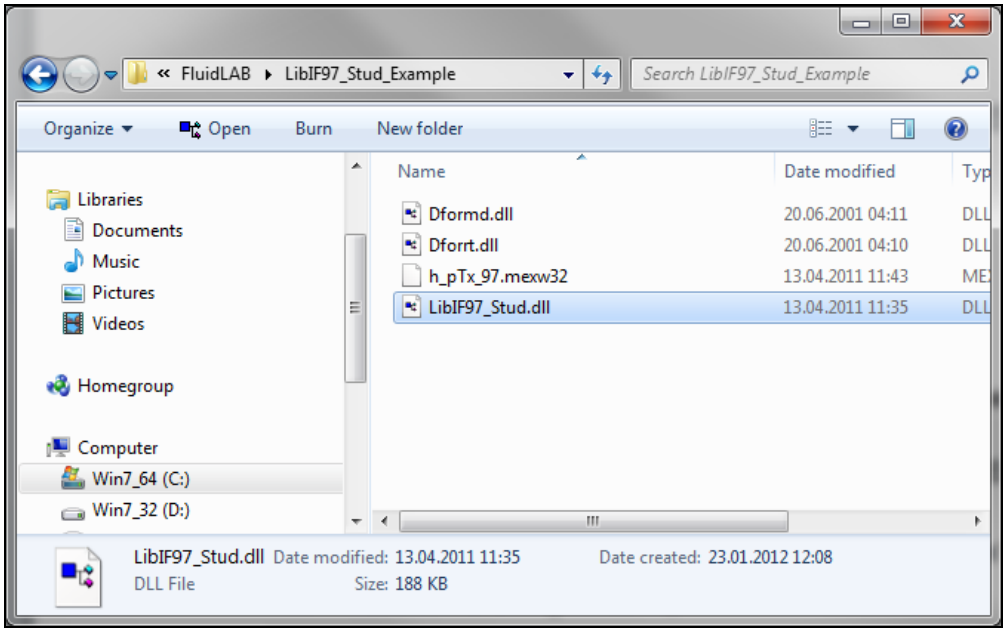


Figure 3.5: Contents of the folder "LibIF97_Stud_Example"

If you have installed the 64-bit version of LibIF97_Stud you will now have to copy the following files into the directory "C:\Program Files\FluidLAB\LibIF97_Stud_Example" in order to calculate the function $h = f(p,T,x)$.

- The following files are needed:
    - "h_pTx_97.mexw64"
    - "LibIF97_Stud.dll"
    - "libifcoremd.dll"
    - "libmmd.dll."
- Click the file "h_pTx_97.mexw64", then click "Edit" in the upper menu bar and select "Copy."
- Switch into the directory "C:\Program Files\FluidLAB\LibIF97_Stud_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:

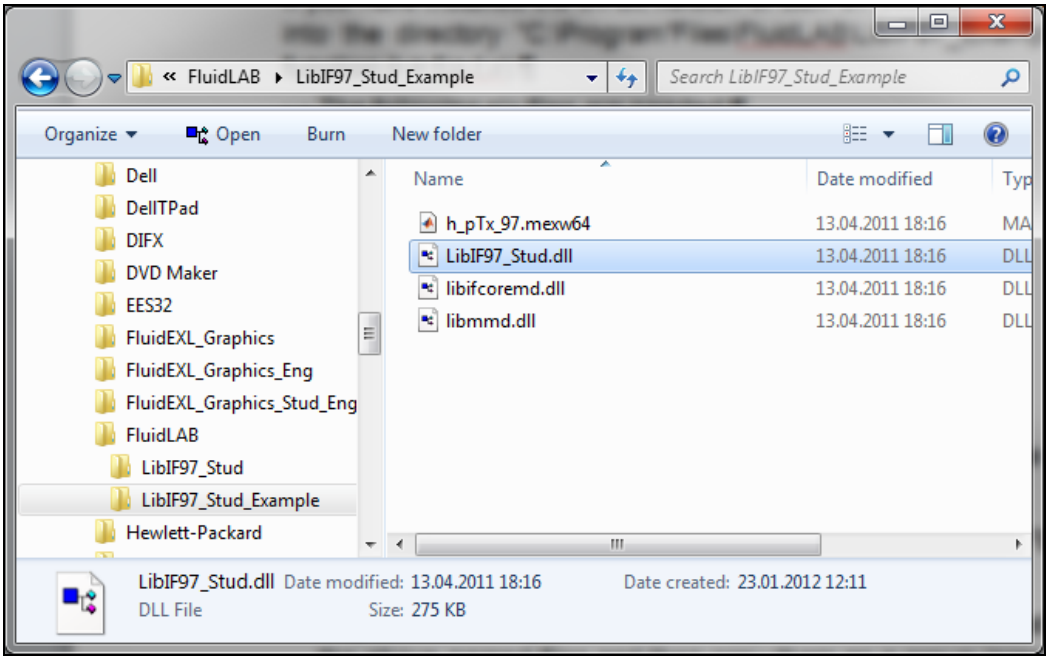


Figure 3.6: Contents of the folder "LibIF97_Stud_Example"

- Start MATLAB® (if you have not started it before).
- Click the button marked in the next figure in order to open the folder "\LibIF97_Stud_Example" in the "Current Folder" window.

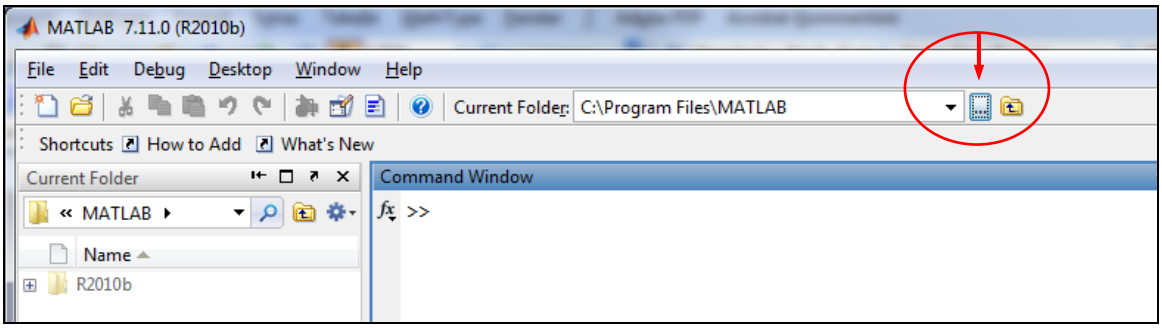


Figure 3.7: Selection of the working directory

- Find and select the directory "C:\Program Files\FluidLAB\LibIF97_Stud_Example" in the pop-up menu (see Figure 3.8).

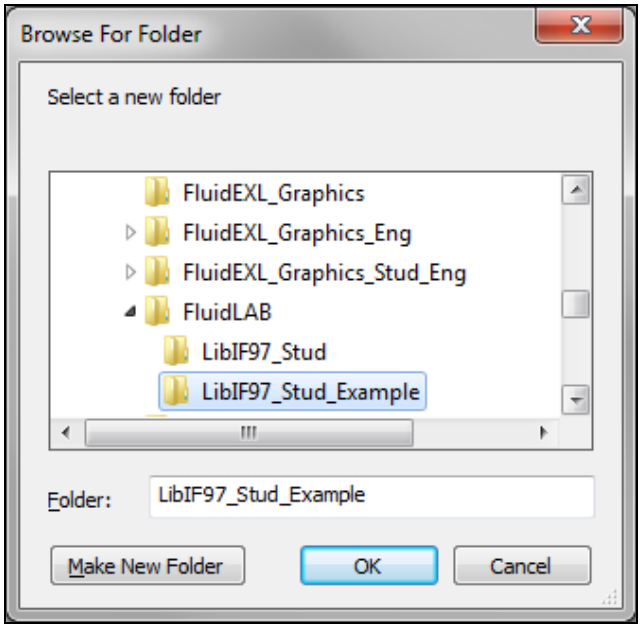


Figure 3.8: Choosing the "LibIF97_Stud_Example" folder

- 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.

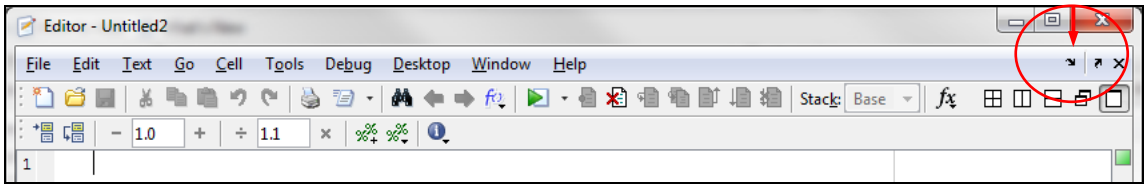


Figure 3.9: Embedding the "Editor" window

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

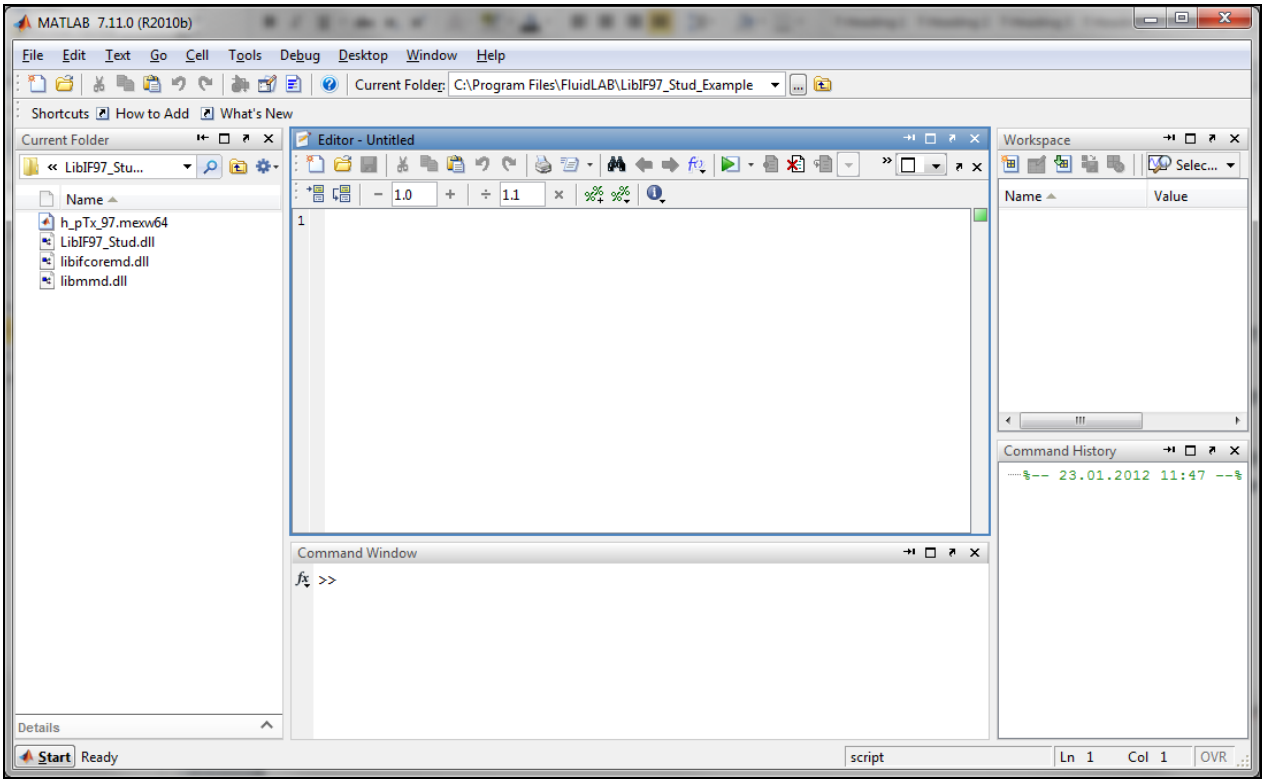


Figure 3.10: Embedded "Editor" window

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

Text to be written:	Explanation:
`% h_pTx_97.m`	file name as comment
`%%`	paragraph separation
`p=10; % pressure in MPa`	declaration of the variables pressure, temperature, art and composition of mixture
`T=673.15; % temperature in K`	
`x=-1; % vapor fraction in kg/kg`	
`%%`	paragraph separation
`h=h_pTx_97(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
  (IF97 range of validity: p = 0.0006112 MPa ... 100 MPa)
- Second operand: Value for T = 673.15 K
  (IF97 range of validity: T = 273.15 ... 1073.15 K)
- 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 –1.

(Wet-steam region of IAPWS-IF97: T = 273.15 K ... T = 647.096 K
p = 0.0006112 MPa ... p = 22.064 MPa)

- 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 "LibIF97_Stud_Example" must be displayed in the "Save in:" field.
- Next to "File name" you have to type "Example_h_pTx_97.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_97.m" in this case. Otherwise an error message will appear during the calculation.

- You will now see the following window:

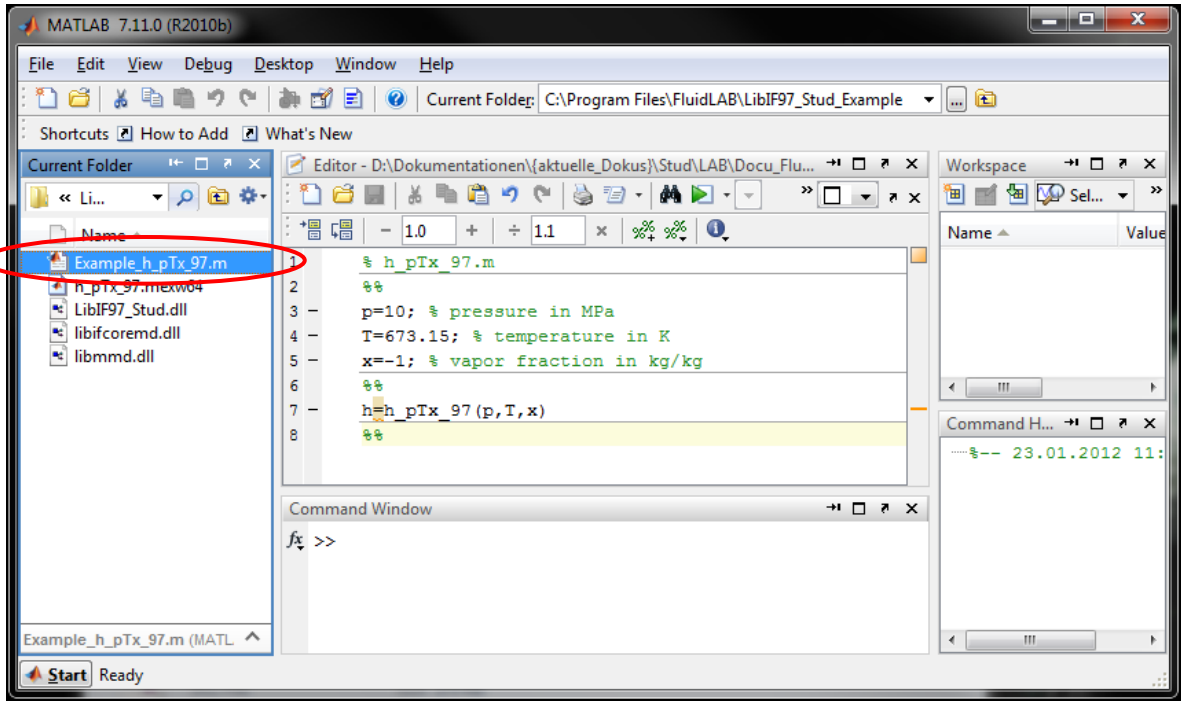


Figure 3.11: "Example_h_pTx_97.m" M-file

- Within the "Current Folder" window, the file "Example_h_pTx_97.m" appears.
- Right-click on this file and select "Run" in the menu which appears (see next image).

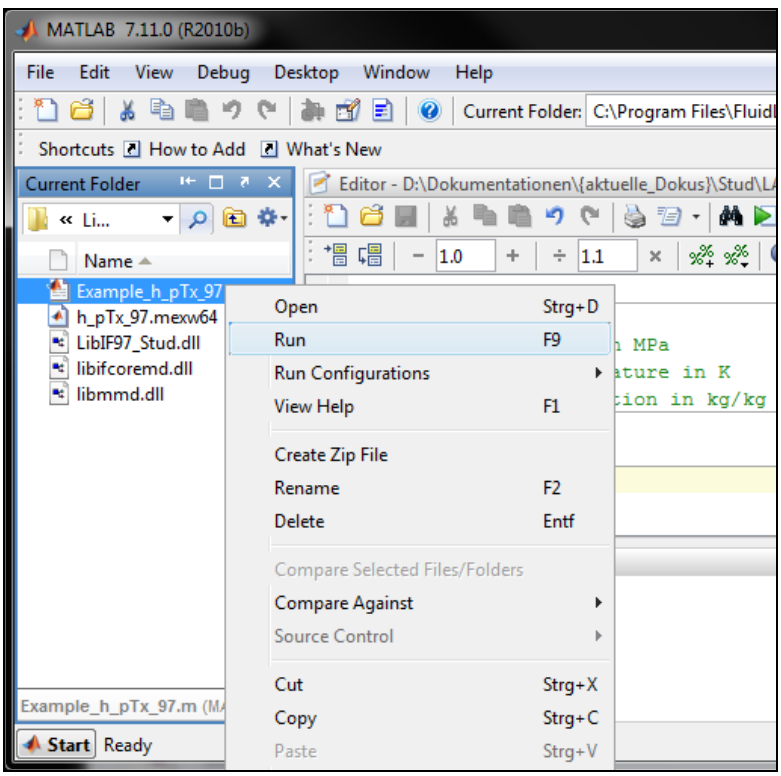


Figure 3.12: Running the "Example_h_pTx_97.m" M-file

- You will see the following window:

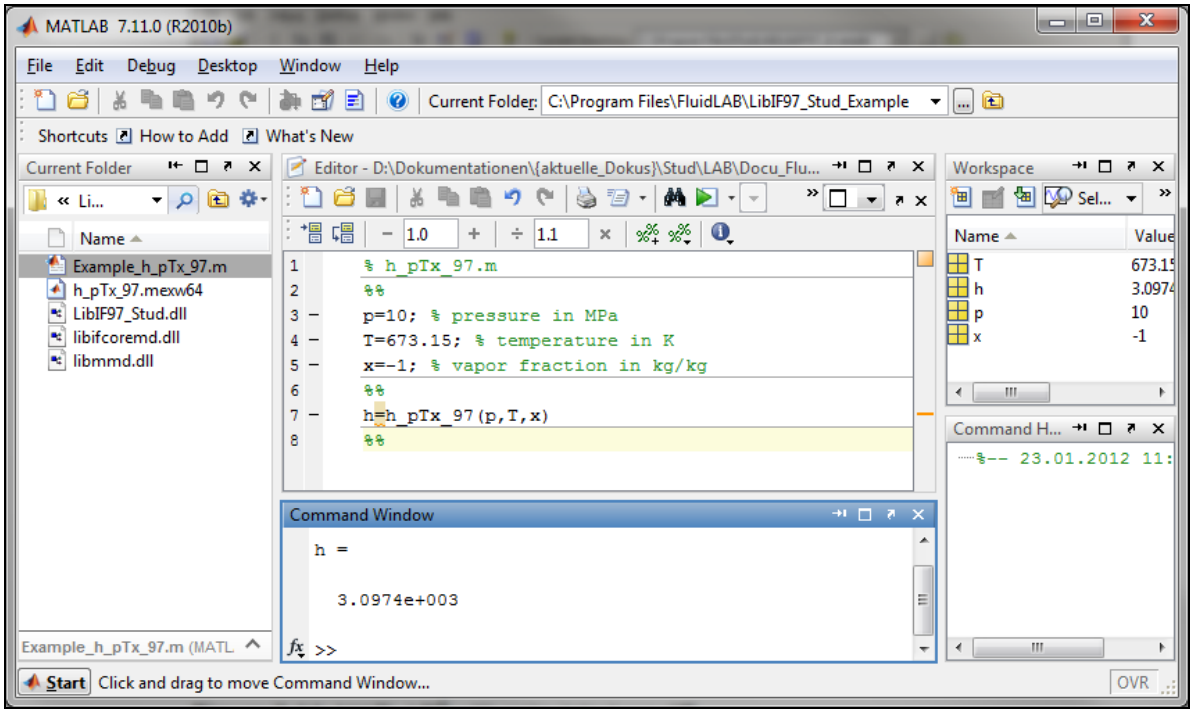


Figure 3.13: MATLAB® with calculated result

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

⇒ The result in our sample calculation here is: "h = 3.0974e+003". The corresponding unit is kJ/kg (see table of the property functions in Chapter 1).

To be able to calculate other values, you have to copy the associated mexw32 or mexw64 files as well because MATLAB® can only access functions that are located in the "Current Directory" window. The example calculated can be found in the directory C:\Program Files\FluidLAB\LibIF97_Stud_Example," and you may use it as a basis for further calculations using FluidLAB.

3.3 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 "\LibIF97_Stud_Example" in the window "Current Folder."

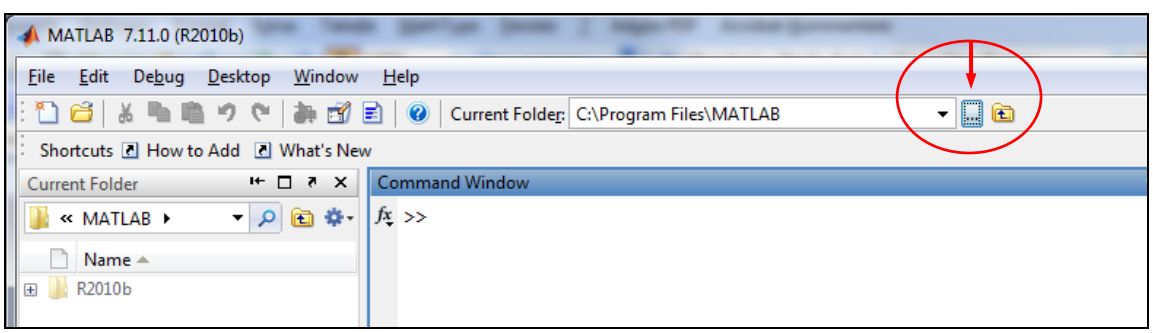


Figure 3.14: Selection of the working directory

- Find and select the directory "C:\Program Files\FluidLAB\LibIF97_Stud_Example"

in the menu which appears (see Figure 3.15).

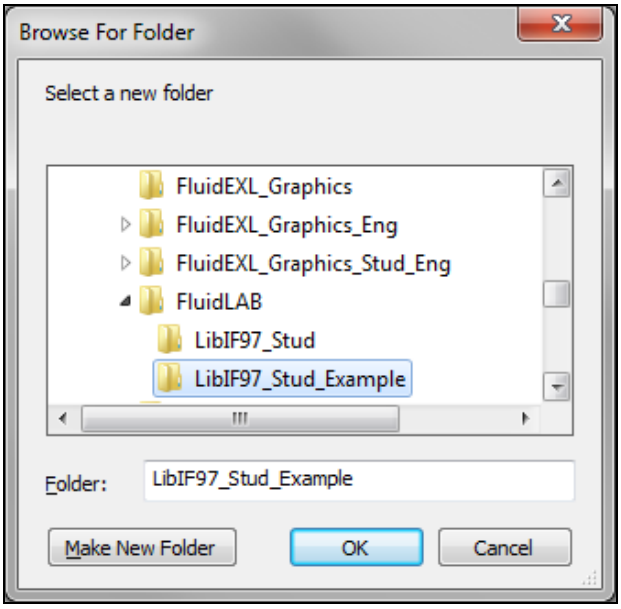


Figure 3.15: Choosing the "LibIF97_Stud_Example" folder

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

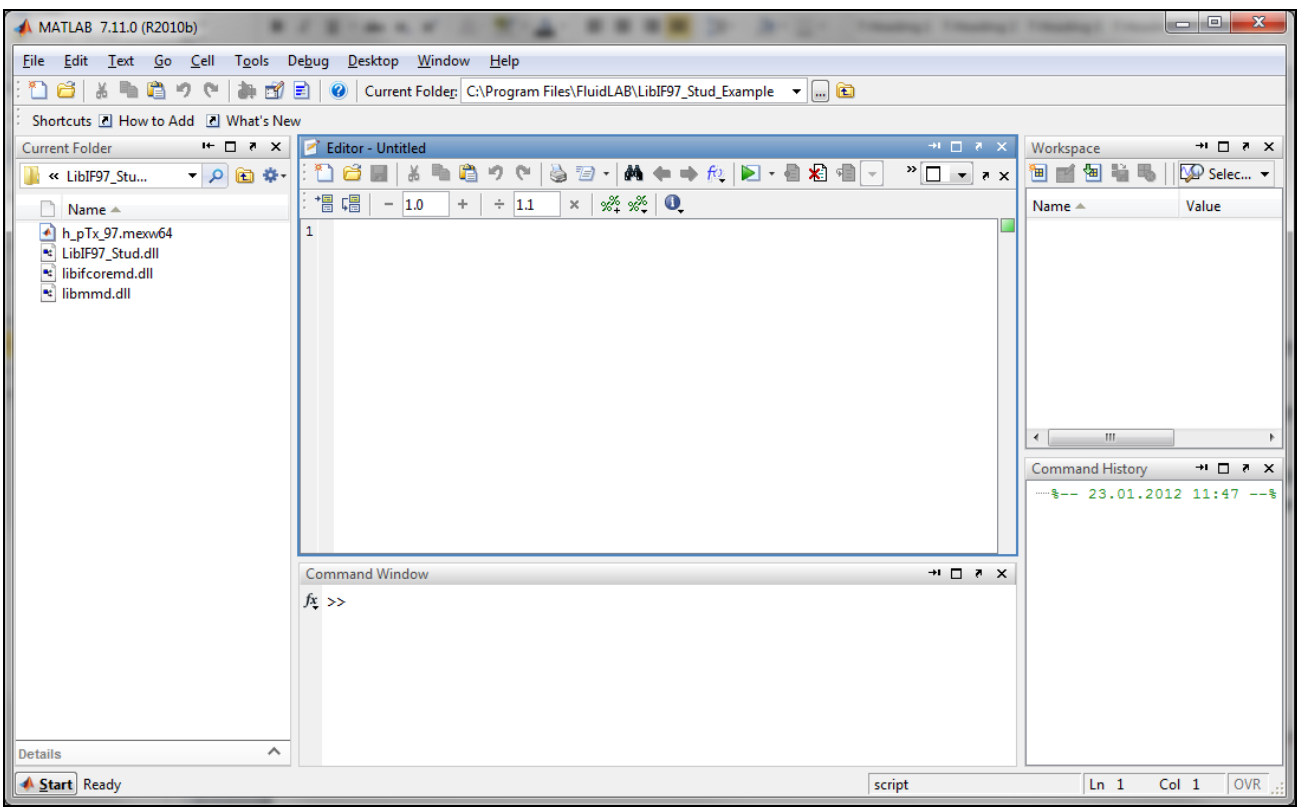


Figure 3.16: MATLAB® with necessary files

Corresponding to the table of the property functions in Chapter 1 you have to call up the function "**h_pTx_97**" as follows for calculating $h = f(p,T,x)$.

Write "**h=h_pTx_97(10,673.15,-1)**" within the "Command Window"

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

- First operand: Value for p = 10 MPa
  (IF97 range of validity: p = 0.0006112 MPa ... 100 MPa)
- Second operand: Value for T = 673.15 K
  (IF97 range of validity: T = 273.15 ... 1073.15 K)
- 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 –1.

(Wet-steam region of IAPWS-IF97: T = 273.15 K ... T = 647.096 K
p = 0.0006112 MPa ... p = 22.064 MPa)

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

- You will see the following window:

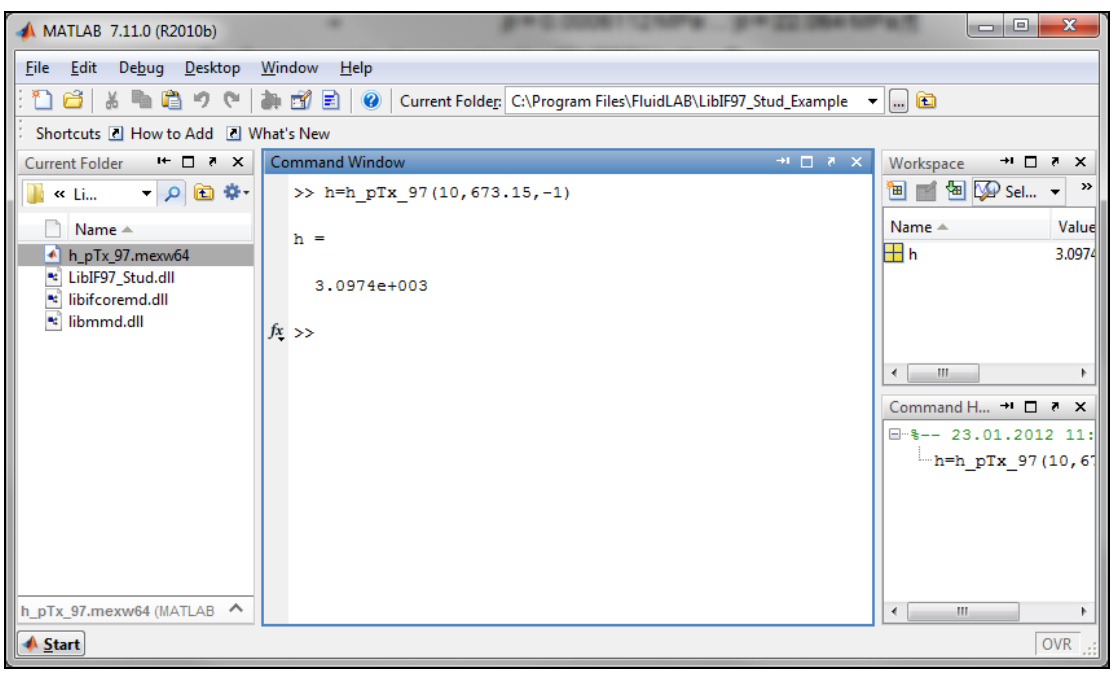


Figure 3.17: MATLAB® with calculated result

⇒ In the "Command Window" you will see the result "h = 3.0974e+033". The corresponding unit is kJ/kg (see table of the property functions in Chapter 1).

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

3.4 Removing FluidLAB including LibIF97_Stud

To remove the LibIF97_Stud property library 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_LibIF97_Stud" (32-bit version of FluidLAB LibIF97_Stud)

"FluidLAB_LibIF97_Stud_64" (64-bit version of FluidLAB LibIF97_Stud)

by clicking on it and click the "Change/Remove" button.

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

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

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

Now, FluidLAB has been removed.

If there is no other library than LibIF97_Stud installed then the directory "FluidLAB" will be removed as well.

4. Program Documentation

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

Function Name:	**cp_pTx_97**
Subprogram with value of the function: For the call out of FORTRAN:	**REAL*8 FUNCTION CPPTX97(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: For the call out of the DLL:	**INTEGER*4 FUNCTION C_CPPTX97(CP,P,T,X)** REAL*8 CP,P,T,X

Input values

p - Pressure p in MPa

T - Temperature T in K

x - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

CPPTX97, CP or **cp_pTx_97** - Specific isobaric heat capacity c_p in kJ/kg K

Range of validity

Temperature range: from 273.15 K to 1073.15 K

Pressure range: from 0.000611 MPa to 100 MPa

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 = -1, or the given value for p <u>and</u> t = -1, 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 = 273.15 K to T = 647.096 K

Pressure ranges from p = 0.000611 MPa to p = 22.064 MPa)

Results for wrong input values

Wrong input values(see below) result in **CPPTX97, CP = -1** or **cp_pTx_97 = -1**.

Single-phase region: (x = - 1)	p > 100 MPa or p < 0.000611 MPa or T > 2273.15 K or T < 273.15 K or T > 1073.15 K at p > 10 MPa
Saturated liquid or vapor line: (x = 0 or x = 1)	at p = - 1 and T > 647.096 K or T < 273.15 K or at T = - 1 and p > 22.064 MPa or p < 0.000611 MPa or at p > 22.064 MPa or p < 0.000611 MPa and T > 647.096 K or T < 273.15 K at $\lvert T-T_s(p)\rvert$ > 0.1 K

References: [1], [2], [3]

Dynamic Viscosity η = f(p,T,x)

Function Name:	**eta_pTx_97**
Subprogram with value of the function: For the call out of FORTRAN:	**REAL*8 FUNCTION ETAPTX97(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: For the call out of the DLL:	**INTEGER*4 FUNCTION C_ETAPTX97(ETA,P,T,X)** REAL*8 ETA,P,T,X

Input values

p - Pressure p in MPa

T - Temperature T in K

x - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

ETAPTX97, ETA or **eta_pTx_97** – Dynamic viscosity η in Pa s

Range of validity

Temperature range: from 273.15 K to 1073.15 K

Pressure range: from 0.000611 MPa to 100 MPa

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 = -1, or the given value for p <u>and</u> t = -1, 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 = 273.15 K to T = 647.096 K

Pressure ranges from p = 0.000611 MPa to p = 22.064 MPa)

Results for wrong input values

Wrong input values(see below) result in **ETAPTX97, ETA = - 1** or **eta_pTx_97 = - 1.**

Single-phase region: (x = - 1)	p > 100 MPa or p < 0.000611 MPa or T > 1073.15 K or T < 273.15 K
Saturated liquid or vapor line: (x = 0 or x = 1)	at p = - 1 and T > 647.096 K or T < 273.15 K or at T = - 1 and p > 22. 064 MPa or p < 0.000611 MPa or at p > 22.064 MPa or p < 0.000611 MPa and T > 647.096 K or T < 273.15 K at $\lvert T-T_s(p)\rvert$ > 0.1 K

References: [5], internal calculation of ρ or v corresponding to: [1], [2], [3]

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

Function Name:	**h_pTx_97**
Subprogram with value of the function: For the call out of FORTRAN:	**REAL*8 FUNCTION HPTX97(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: For the call out of the DLL:	**INTEGER*4 FUNCTION C_HPTX97(H,P,T,X)** REAL*8 H,P,T,X

Input values

p - Pressure *p* in MPa

T - Temperature *T* in K

x - Vapor fraction *x* in (kg saturated steam)/(kg wet steam)

Result

HPTX97, H or **h_pTx_97** - Specific enthalpy *h* in kJ/kg

Range of validity

Temperature range: from 273.15 K to 1073.15 K

Pressure range: from 0.000611 MPa to 100 MPa

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 = -1 or the given value for *p* <u>and</u> T = -1 and in both cases the value for *x* between 0 and 1 must be entered.

If *p* <u>and</u> *T* <u>and</u> *x* are entered as given values, the program considers *p* and *T* to be appropriate to represent the vapor pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1.

(Wet steam region of the IAPWS-IF97:

Temperature ranges from T = 273.15 K to T = 647.096 K

Pressure ranges from p = 0.000611 MPa to p = 22.064 MPa)

Results for wrong input values

Wrong input values(see below) result in **HPTX97, H = - 1** or **h_pTx_97 = - 1**.

Single-phase region: (x = - 1)	p > 100 MPa or p < 0.000611 MPa or T > 2273.15 K or T < 273.15 K or T > 1073.15 K at p > 10 MPa
Wet steam region: (0 <= x <= 1)	at p = - 1 and T > 647.096 K or T < 273.15 K or at T = - 1 and p > 22.064 MPa or p < 0.000611 MPa or at p > 22.064 MPa or p < 0.000611 MPa and T > 647.096 K or T < 273.15 K at $\lvert T-T_S(p)\rvert$ > 0.1 K

References: [1], [2], [3]

Thermal Conductivity λ = f(p,T,x)

Function Name:	**lambda_pTx_97**
Subprogram with value of the function: For the call out of FORTRAN:	**REAL*8 FUNCTION LAMPTX97(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: For the call out of the DLL:	**INTEGER*4 FUNCTION C_LAMPTX97(LAM,P,T,X)** REAL*8 LAM,P,T,X

Input values

p - Pressure p in MPa

T - Temperature T in K

x - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

LAMPTX97, **LAM** or **lambda_pTx_97** - Thermal conductivity λ in W/m·K

Range of validity

Temperature range: from 273.15 K to 1073.15 K

Pressure range: from 0.000611 MPa to 100 MPa

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 = -1, or the given value for p <u>and</u> t = -1, 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 = 273.15 K to T = 647.096 K
Pressure ranges from	p = 0.000611 MPa to p = 22.064 MPa)

Results for wrong input values

Wrong input values(see below) result in **LAMPTX97, LAM = - 1** or **lambda_pTx_97 = - 1**.

Single-phase region: (x = - 1)	p > 100 MPa or p < 0.000611 MPa or T > 1073.15 K or T < 273.15 K
Saturated liquid or vapor line: (x = 0 or x = 1)	at p = - 1 and T > 647.096 K or T < 273.15 K or at T = - 1 and p > 22.064 MPa or p < 0.000611 MPa or at p > 22.064 MPa or p < 0.000611 MPa and T > 647.096 K or T < 273.15 K at $\lvert T-T_s(p)\rvert$ > 0.1 K

References: [4], internal calculation of ρ or v corresponding to: [1], [2], [3]

Saturation Pressure p_s = f(T)

Function Name:	**ps_T_97**
Subprogram with value of the function: For the call out of FORTRAN:	**REAL*8 FUNCTION PST97(T)** REAL*8 T
Subprogram with parameter: For the call out of the DLL:	**INTEGER*4 FUNCTION C_PST97(PS,T)** REAL*8 PS,T

Input values

T - Temperature T in K

Result

PST97, PS or **ps_T_97** – Saturation pressure p_s in MPa

Range of validity

from T = 273.15 K to T = 647.096 K

Results for wrong input values

Wrong input values(see below) result in **PST97, PS = -1** or **ps_T_97 = -1**.

T < 273.15 K or T > 647.096 K

References: [1], [2], [3]

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

Function Name:	**s_pTx_97**
Subprogram with value of the function: For the call out of FORTRAN:	**REAL*8 FUNCTION SPTX97(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: For the call out of the DLL:	**INTEGER*4 FUNCTION C_SPTX97(S,P,T,X)** REAL*8 S,P,T,X

Input values

p - Pressure *p* in MPa

T - Temperature *T* in K

x - Vapor fraction *x* in (kg saturated steam)/(kg wet steam)

Result

SPTX97, S or **s_pTx_97** - Specific entropy *s* in kJ/kg K

Range of validity

Temperature range: from 273.15 K to 1073.15 K

Pressure range: from 0.000611 MPa to 100 MPa

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 = -1 or the given value for *p* <u>and</u> T = -1 and in both cases the value for *x* between 0 and 1 must be entered.

If *p* <u>and</u> *T* <u>and</u> *x* are entered as given values, the program considers *p* and *T* to be appropriate to represent the vapor pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1.

(Wet steam region of the IAPWS-IF97:

Temperature ranges from T = 273.15 K to T = 647.096 K

Pressure ranges from p = 0.000611 MPa to p = 22.064 MPa)

Results for wrong input values

Wrong input values(see below) result in **SPTX97, S = - 1** or **s_pTx_97 = - 1**.

Single-phase region: (x = - 1)	p > 100 MPa or p < 0.000611 MPa or T > 2273.15 K or T < 273.15 K or T > 1073.15 K at p > 10 MPa
Wet steam region: (0 <= x <= 1)	at p = - 1 and T > 647.096 K or T < 273.15 K or at T = - 1 and p > 22. 064 MPa or p < 0.000611 MPa or at p > 22.064 MPa or p < 0.000611 MPa and T > 647.096 K or T < 273.15 K at $\lvert T-T_s(p)\rvert$ > 0.1 K

References: [1], [2], [3]

[#K$+]Backward Function: Temperature *T* = f(*p*,*h*)

Function Name:	**T_ph_97**
Subprogram with value of the function: For the call out of FORTRAN:	**REAL*8 FUNCTION TPH97(P,H)** REAL*8 P,H
Subprogram with parameter: For the call out of the DLL:	**INTEGER*4 FUNCTION C_TPH97(T,P,H)** REAL*8 T,P,H

Input values

p - Pressure *p* in MPa

h - Specific enthalpy *h* in kJ/kg

Result

TPH97, T or **T_ph_97** - Temperature *T* in K

Range of validity

Pressure range:	from 0.000611 MPa to 100 MPa
Enthalpy range:	corresponding to temperatures from 273.15 K to 1073.15 K

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 = 0.000611 MPa to p = 22.064 MPa

Results for wrong input values

Wrong input values(see below) result in **TPH97, T = - 1** or **T_ph_97 = - 1**.

Single-phase region:	p > 100 MPa or p < 0.000611 MPa or when calculation results in T > 2273.15 K or T < 273.15 K or T > 1073.15 K at p > 10 MPa
Wet steam region:	p > 22.064 MPa or p < 0.000611 MPa or when calculation results in T > 647.096 K or T < 273.15 K

References: [1], [2], [3]

[#] FUNC_97_200
[K] Backward Function: Temperature, t = f(p,h)
[$] Backward Function: Temperature t = f(p,h)
[+] SUCH:200

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

Function Name:	**T_ps_97**
Subprogram with value of the function: For the call out of FORTRAN:	**REAL*8 FUNCTION TPS97(P,S)** REAL*8 P,S
Subprogram with parameter: For the call out of the DLL:	**INTEGER*4 FUNCTION C_TPS97(T,P,S)** REAL*8 T,P,S

Input values

p - Pressure *p* in MPa

s - Specific entropy *s* in kJ/kg K

Result

TPS97, T or **T_ps_97** - Temperature *T* in K

Range of validity

Pressure range:	from 0.000611 MPa to 100 MPa
Enthalpy range:	corresponding to temperatures from 273.15 K to 1073.15 K

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 = 0.000611 MPa to p = 22.064 MPa

Results for wrong input values

Wrong input values(see below) result in **TPS97, T = - 1** or **T_ps_97 = - 1**.

Single-phase region:	p > 100 MPa or p < 0.000611 MPa or when calculation results in T > 2273.15 K or T < 273.15 K or T > 1073.15 K at p > 10 MPa
Wet steam region:	p > 22.064 MPa or p < 0.000611 MPa or when calculation results in T > 647.096 K or T < 273.15 K

References: [1], [2], [3]

Saturation Temperature T_s = f(p)

Function Name:	**Ts_p_97**
Subprogram with value of the function: For the call out of FORTRAN:	**REAL*8 FUNCTION TSP97(P)** REAL*8 P
Subprogram with parameter: For the call out of the DLL:	**INTEGER*4 FUNCTION C_TSP97(TS,P)** REAL*8 TS,P

Input values

p - Pressure p in MPa

Result

TSP97, T or **Ts_p_97** - Saturation temperature T_s in K

Range of validity

from p = 0.000611 MPa to p = 22.064 MPa

Results for wrong input values

Wrong input values(see below) result in **TSP97, T = - 1** or **Ts_p_97 = - 1**.

p < 0.000611 MPa or p > 22.064 MPa

References: [1], [2], [3]

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

Function Name:	**v_pTx_97**
Subprogram with value of the function: for the call out of FORTRAN:	**REAL*8 FUNCTION VPTX97(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: for the call out of the DLL:	**INTEGER*4 FUNCTION C_VPTX97(V,P,T,X)** REAL*8 V,P,T,X

Input values

p - Pressure *p* in MPa

T - Temperature *T* in K

x - Vapor fraction *x* in (kg saturated steam)/(kg wet steam)

Result

VPTX97, V or **v_pTx_97** - Specific volume *v* in m^3/kg

Range of validity

Temperature range: from 273.15 K to 1073.15 K

Pressure range: from 0.000611 MPa to 100 MPa

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 = -1 or the given value for *p* <u>and</u> T = -1 and in both cases the value for *x* between 0 and 1 must be entered.

If *p* <u>and</u> *T* <u>and</u> *x* are entered as given values, the program considers *p* and *T* to be appropriate to represent the vapor pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1.

(Wet steam region of the IAPWS-IF97:

Temperature ranges from T = 273.15 K to T = 647.096 K

Pressure ranges from p = 0.000611 MPa to p = 22.064 MPa)

Results for wrong input values

Wrong input values(see below) result in **VPTX97, V = - 1** or **v_pTx_97 = - 1**.

Single-phase region: (x = - 1)	p > 100 MPa or p < 0.000611 MPa or T > 2273.15 K or T < 273.15 K or T > 1073.15 K at p > 10 MPa
Wet steam region: (0 <= x <= 1)	at p = - 1 and T > 647.096 K or T < 273.15 K or at T = - 1 and p > 22.064 MPa or p < 0.000611 MPa or at p > 22.064 MPa or p < 0.000611 MPa and T > 647.096 K or T < 273.15 K at $\lvert T-T_s(p)\rvert$ > 0.1 K

References: [1], [2], [3]

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

Function Name:	**x_ph_97**
Subprogram with value of the function: For the call out of FORTRAN:	**REAL*8 FUNCTION XPH97(P,H)** REAL*8 P,H
Subprogram with parameter: For the call out of the DLL:	**INTEGER*4 FUNCTION C_XPH97(X,P,H)** REAL*8 X,P,H

Input values

p - Pressure *p* in MPa

h - Specific enthalpy *h* in kJ/kg

Result

XPH97, X or **x_ph_97** - Vapor fraction *x* in (kg saturated steam)/(kg wet steam)

Range of Validity

Pressure range:	from 0.000611 MPa to 100 MPa
Enthalpy range:	corresponding to temperatures from 273.15 K to 1073.15 K

Details on the calculation of wet steam

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

Wet steam region: Pressure ranges from p = 0.000611 MPa to p = 22.064 MPa

Results for wrong input values

Wrong input values(see below) result in **XPH97, X = - 1** or **x_ph_97 = - 1**.

If the state point to be calculated is located within the single-phase region
$p > 22.064$ MPa or $p < 0.000611$ MPa

References: [1], [2], [3]

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

Function Name:	**x_ps_97**
Subprogram with value of the function: For the call out of FORTRAN:	**REAL*8 FUNCTION XPS97(P,S)** REAL*8 P,S
Subprogram with parameter: For the call out of the DLL:	**INTEGER*4 FUNCTION C_XPS97(X,P,S)** REAL*8 X,P,S

Input values

p - Pressure *p* in MPa

s - Specific entropy *s* in kJ/kg K

Result

XPS97, X or **x_ps_97** - Vapor fraction *x* in (kg saturated steam)/(kg wet steam)

Range of validity

Pressure range:	from 0.000611 MPa to 100 MPa
Entropy range:	corresponding to temperatures from 273.15 K to 1073.15 K

Details on the calculation of wet steam

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

Wet steam region: Pressure ranges from p = 0.000611 MPa to p = 22.064 MPa

Results for wrong input values

Wrong input values(see below) result in **XPS97, X = - 1** or **x_ps_97 = - 1**.

If the state point to be calculated is located within the single-phase region
p > 22.064 MPa or p < 0.000611 MPa

References: [1], [2], [3]

ZITTAU/GOERLITZ UNIVERSITY OF APPLIED SCIENCES
Department of Technical Thermodynamics
www.thermodynamic-property-libraries.com

5. Property Libraries for Calculating Heat Cycles, Boilers, Turbines, and Refrigerators

Steam, Water and Ice

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 Thermodyn. Derivatives (2008)
- Ice from IAPWS-Formulation 2006

Humid Combustion Gas Mixtures

Library LibHuGas

Ideal mixture of the real fluids:

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

and of the ideal gases:

SO_2, CO, Ne (scientific equations of Bücker et al.)
Consideration of

Dissociation from VDI 4670 and Poynting effect

Library LibIDGAS

Ideal gas mixture calculated from VDI-Guideline 4670

Humid Air

Library LibHuAir

Ideal mixture of the real fluids:

- Dry air from Lemmon et al.
- Steam and water from IAPWS-95

Consideration of

- Dissociation from VDI-Guideline 4670
- Poynting effect

Library LibIdAir

Ideal gas mixture (VDI-Guideline 4670)

Carbon Dioxide

Library LibCO2

Formulation of Span and Wagner (1994)

Hydrogen

Library LibH2

Formulation of Leachman et al. (2007)

Methanol

Library LibCH3OH

Formulation of de Reuck and Craven (1993)

Ethanol

Library LibC2H5OH

Formulation of Dillon and Pennoncello (2004)

Ideal Gas Mixtures

Library LibIdGasMix

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 VDI-Guideline 4670

Dry Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Nitrogen

Library LibN2

Formulation of Span et al. (2000)

Seawater

Library LibSeaWa

IAPWS Formulation 2008 of Feistel and IAPWS-IF97

Ammonia

Library LibNH3

Formulation of Tillner-Roth (1995)

Propane

Library LibPropan

Formulation of Lemmon et al. (2007)

Helium

Library LibHe

Formulation of McCarty and Arp (1990)

Siloxanes as ORC Working Fluids

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

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

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

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

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

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

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

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

Formulations of Colonna et al. (2006 and 2008)

Mixtures for Absorption Processes

Library LibAmWa

Ammonia/Water Mixtures

IAPWS Guideline 2001 of Tillner-Roth and Friend (1998)

Helmholtz energy equation for the mixing term (useable for calculating Kalina Cycle)

Library LibWaLi

Water/Lithium Bromide Mixtures

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Refrigerants

Library LibR134a

R134a

Formulation of Tillner-Roth and Baehr (1994)

Library LibButan_Iso

Iso-Butane

Formulation of Bücker et al. (2003)

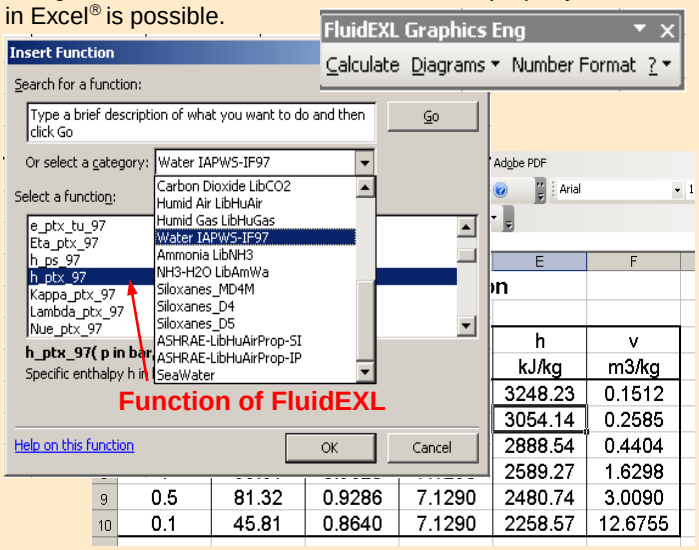
Library LibButan_n

n-Butane

Formulation of Bücker et al. (2003)

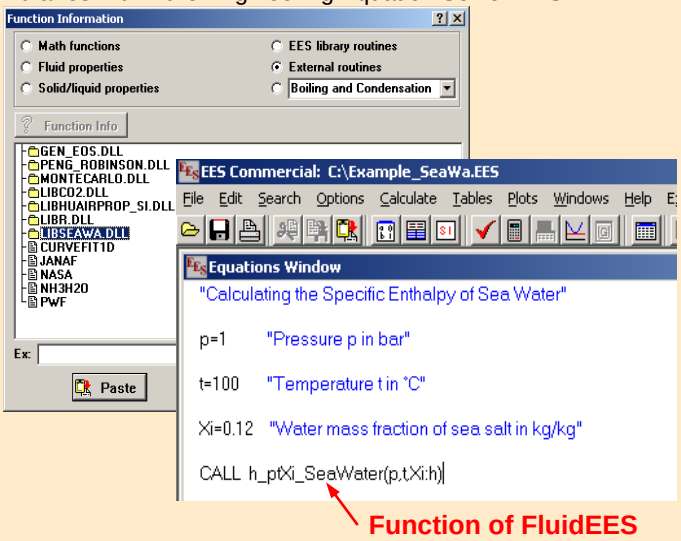
Add-In FluidEXL for Excel®

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



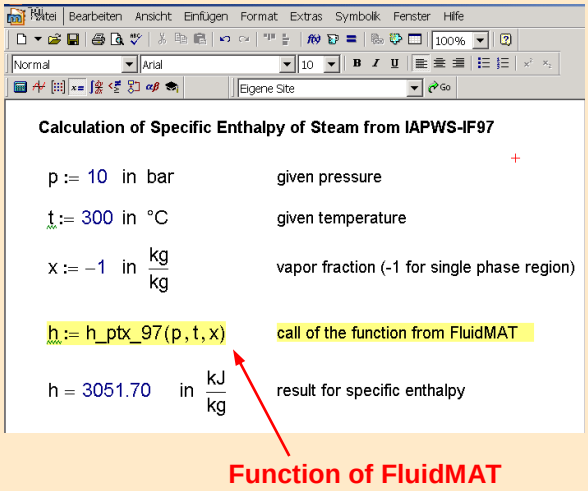
Add-In FluidEES for EES®

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



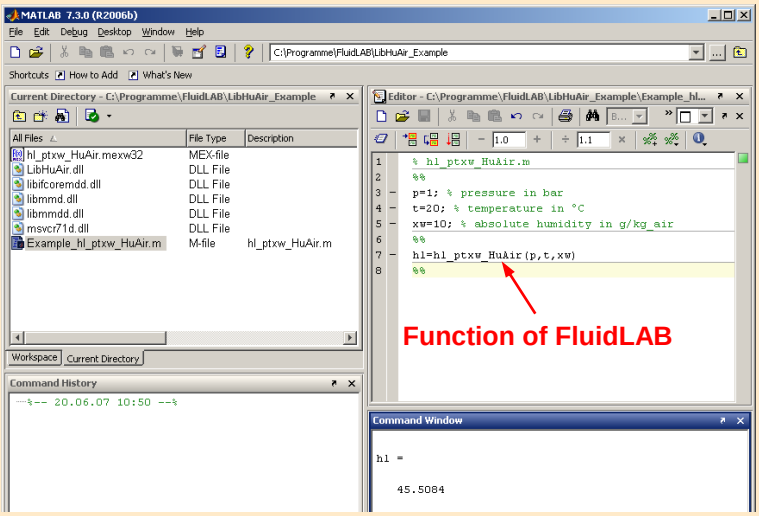
Add-In FluidMAT for Mathcad®

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



Add-In FluidLAB for MATLAB®

The property functions can be called in MATLAB®.



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

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

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

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

6. References

[1] IAPWS Secretariat, Dooley, B., EPRI, Palo Alto CA (1997):
Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam IAPWS-IF97. Available at www.iapws.org.

[2] Wagner, W.; Kretzschmar, H.-J. (2008):
International Steam Tables. Springer-Verlag, Berlin, www.international-steam-tables.com

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[4] IAPWS Secretariat, Dooley, B., EPRI, Palo Alto CA (1998):
Revised Release on the IAPS Formulation 1985 for the Thermal Conductivity of Ordinary Water Substance. Available at www.iapws.org.

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