Property Library for Combustion Gas Mixtures Calculated from VDI-Guideline 4670

FluidLAB
with LibIdGas
for MATLAB®
and Simulink®

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Property Software for Combustion Gases Calculated as Ideal Mixture of Ideal Gases from VDI-Guideline 4670

FluidLAB

for MATLAB®

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_LibIDGAS.zip"

Combustion Gases calculated from VDI-Guideline 4670

Including the following files:

FluidLAB_LibIDGAS_Setup.exe	- Installation program for the FluidLAB Add-On for use in MATLAB®
LibIDGAS.dll	- Dynamic Link Library for ideal gas for use in MATLAB®
FluidLAB_LibIDGAS_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_LibIDGAS_x64.zip"

Combustion Gases calculated from VDI-Guideline 4670

Including the following files and folders:

Files:

Setup.exe	- Self-extracting and self-installing program for FluidLAB
FluidLAB_LibIDGAS_64.msi	- Installation program for the FluidLAB Add-On for use in MATLAB®
LibIDGAS.dll	- Dynamic Link Library for ideal gas for use in MATLAB®
FluidLAB_LibIDGAS_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. Property Functions

1.1 Range of Validity and Structure of the Program Library

The thermodynamic properties of combustion gas mixtures in the ideal gas state are calculated corresponding to the

VDI Guideline 4670 [21].

The transport properties are calculated corresponding to

Brandt [15] and VDI-Wärmeatlas [19].

Important property constants were taken from the compendium from *Blanke* [20].

The mixture can contain the following components:

Number	Component	
1	Argon	Ar
2	Neon	Ne
3	Nitrogen	N_2
4	Oxygen	O_2
5	Carbon monoxide	CO
6	Carbon dioxide	CO_2
7	Steam	H_2O
8	Sulfur dioxide	SO_2
9	Air (dry)	
10	Air nitrogen	

Range of validity:

Temperature *t*: from -73.15 °C to 3026.85 °C

Mixture pressure *p*: from >0 bar to 10 (30), max 50 bar

The pressure range is limited for gases and mixtures in the ideal gas state.

For temperatures higher than 700 °C the influence of dissociation is taken into consideration.

1.2 Property Functions for Ideal Gas Mixtures

Functional Dependence	Function Name	Call as Fortran Program	Property or Function	Unit of the Result	Reference	Page
$a = f(p,t,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	a_pt_id	a_pt_id(p,t,type,zu(1:10))	Thermal diffusivity	m^2/s	[15], [18]	3/1
$c_p = f(p,t,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	cp_pt_id	cp_pt_id(p,t,type,zu(1:10))	Specific isobaric heat capacity	kJ/(kg · K)	[18]	3/2
$c_v = f(p,t,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	cv_pt_id	cv_pt_id(p,t,type,zu(1:10))	Specific isochoric heat capacity	kJ/(kg · K)	[18]	3/3
$\eta = f(t,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	Eta_t_id	Eta_t_id(t,type,zu(1:10))	Dynamic viscosity	Pa·s = kg/(m·s)	[15], [18]	3/4
$h = f(p,t,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	h_pt_id	h_pt_id(p,t,type,zu(1:10))	Specific enthalpy	kJ/kg	[18]	3/5
$\kappa = f(p,t,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	Kappa_pt_id	Kappa_pt_id(p,t,type,zu(1:10))	Isentropic exponent		[18]	3/6
$\lambda = f(t,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	Lambda_t_id	Lambda_t_id(t,type,zu(1:10))	Thermal conductivity	W/(m · K)	[15]	3/7
$M = f(\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	M_id	M_id(type,zu(1:10))	Molar mass of the mixture	kg/kmol	[17]	3/8
$\nu = f(p,t,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	Ny_pt_id	Ny_pt_id(p,t,type,zu(1:10))	Kinematic Viscosity	m^2/s	[15], [16]	3/9
$p = f(t,s,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	p_ts_id	p_ts_id(t,s,type,zu(1:10))	Backward Function: Mixture pressure from temperature and entropy of the mixture	bar	[18]	3/10
$p = f(t,v,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	p_tv_id	p_tv_id(t,v,type,zu(1:10))	Backward Function Mixture pressure from temperature and specific volume	bar	Ideal gas equation	3/11
$Pr = f(p,t,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	Pr_pt_id	Pr_pt_id(p,t,type,zu(1:10))	*Prandtl*-number		[15], [16]	3/12
$\psi_i = f(i,\xi_1 \ldots \xi_{10})$	Psi_igas_Xsi_id	Psi_igas_Xsi_id(i,Xsi(1:10))	Mole fraction of the mixture gas i from the mass fractions of all mixture gases	kmol/kmol	Mixture calculation	3/13
$R = f(\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	R_id	R_id(type,zu(1:10))	Specific gas constant	kJ/(kg · K)	[17]	3/14
$\rho = f(p,t,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	Rho_pt_id	Rho_pt_id(p,t,type,zu(1:10))	Density	kg/m^3	Ideal gas equation	3/15

Functional Dependence	Function Name	Call as Fortran Program	Property or Function	Unit of the Result	Reference	Page
$s = f(p,t,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	s_pt_id	s_pt_id(p,t,type,zu(1:10))	Specific entropy of the mixture	kJ/(kg · K)	[18]	3/16
$T = f(p,h,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	t_ph_id	t_ph_id(p,h,type,zu(1:10))	Backward Function: Temperature from pressure and enthalpy of the mixture	°C	[18]	3/17
$t = f(p,s,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	t_ps_id	t_ps_id(p,s,type,zu(1:10))	Backward Function: Temperature from pressure and entropy of the mixture	°C	[18]	3/18
$t = f(p,v,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	t_pv_id	t_pv_id(p,v,type,zu(1:10))	Backward Function: Temperature from pressure and specific volume of the mixture	°C	[18]	3/19
$u = f(p,t,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	u_pt_id	u_pt_id(p,t,type,zu(1:10))	Specific internal energy	kJ/kg		3/20
$v = f(p,t,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	v_pt_id	v_pt_id(p,t,type,zu(1:10))	Specific volume	m^3/kg	Ideal gas equation	3/21
$w = f(p,t,\xi_1 \ldots \xi_{10}$ or $\psi_1 \ldots \psi_{10})$	w_pt_id	w_pt_id(p,t,type,zu(1:10))	Isentropic speed of sound of the mixture	m/s	[18]	3/22
$\xi_i = f(i,\psi_1 \ldots \psi_{10})$	Xsi_igas_Psi_id	Xsi_igas_Psi_id(i,Psi(1:10))	Mass fraction of the mixture gas i from the mole fractions of all mixture gases	kg/kg	Mixture calculation	3/23

Units:

Symbol	Name	Unit
t	Temperature	°C
p	Mixture pressure	bar
$\xi_1 \ldots \xi_{10}$	Mass fractions of the components	kg/kg
$\psi_1 \ldots \psi_{10}$	Mole fractions, volume fractions of the components	kmol/kmol
type	Input: type = 1 for mass fractions $\xi_1, \ldots \xi_{10}$ type = 0 for mole fractions $\psi_1, \ldots \psi_{10}$	
comp(1:10) for type =1	Mass fractions $\xi_1, \ldots \xi_{10}$	kg/kg
comp(1:10) for type =0	Mole fractions $\psi_1, \ldots \psi_{10}$	kmol/kmol

Mixture Gases:

Gas	Mixture gas	
1	Argon	Ar
2	Neon	Ne
3	Nitrogen	N_2
4	Oxygen	O_2
5	Carbon monoxide	CO
6	Carbon dioxide	CO_2
7	Steam	H_2O
8	Sulfur dioxide	SO_2
9	Air (dry) from VDI4670 [21]	Composition in mole fractions: 78.1109 % N_2 20.9548 % O_2 0.9343 % Ar Composition in mass fractions: 75.5577 % N_2 23.1535 % O_2, 1.2888 % Ar
10	Air nitrogen from *Brandt* [15]	Composition in mole fractions: 98.8180 % N_2 1.1820 % Ar Composition in mass fractions: 98.3229 % N_2 1.6771 % Ar

Range of Validity:

Temperature:	t = -73.15 °C ... 3026.85 °C
Pressure:	p = 0.01 mbar ... 50 bar

Reference States:

Property	Gases (except steam)	Steam
Pressure	1.01325 bar	0.006112127 bar
Temperature	0.0 °C	0 °C
Enthalpy	0 kJ/kg	2500.9342 kJ/kg
Entropy	0 kJ/kg K	9.15591 kJ/(kg K)

Variable Types for Function Call:

All functions:	Double
Variable p, t, v, h, s :	Double
Variable to [1..10] :	Array of Double
Variable type, i :	Integer

Note:

If the input values are located outside the range of validity or if they do not fit together, the chosen function to be calculated results in -1.

2 Application of FluidLAB in MATLAB

The FluidLAB Add-In has been developed to calculate thermodynamic properties in MATLAB®. Within FluidLAB, it enables the direct call of functions relating to ideal gas from the LibIDGAS property library.

2.1 Installing FluidLAB

Installing FluidLAB including LibIDGAS for 32-bit MATLAB®

This section describes the installation of FluidLAB LibIDGAS 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_LibIDGAS.zip", you will see the folder

CD_FluidLAB_LibIDGAS

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_LibIDGAS_Docu_Eng.pdf
FluidLAB_LibIDGAS_Setup.exe
LibIDGAS.dll.

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

FluidLAB_LibIDGAS_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\LibIDGAS (for English version of Windows)
C:\Programme\FluidLAB\LibIDGAS (for German version of Windows)

By clicking the "Browse…" button, you can change the installation directory before installation (see Figure 2.1).

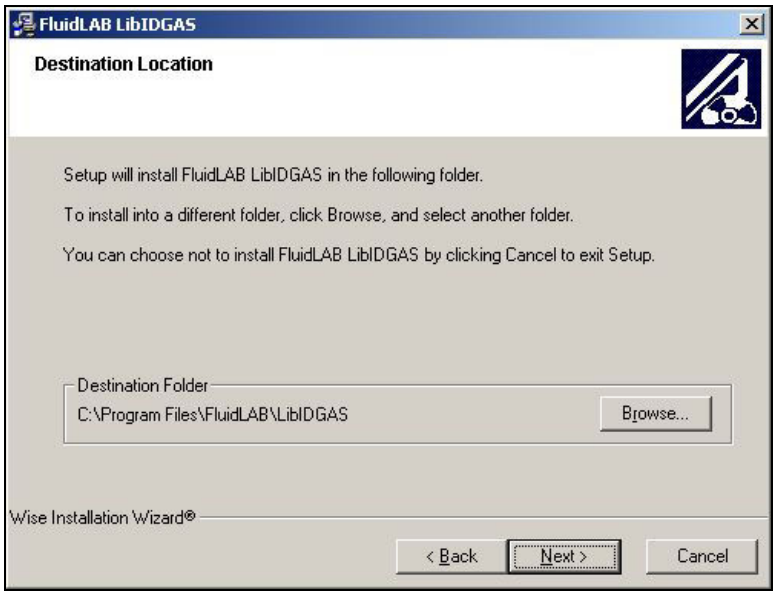

Figure 2.1: "Destination Location"

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 LibIDGAS

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

into the directory

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

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

To do this, open the CD folder in "My Computer" and click on the file "LibIDGAS.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\LibIDGAS (for English version of Windows)
C:\Programme\FluidLAB\LibIDGAS (for German version of Windows))

and insert the file "LibIDGAS.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 "LibIDGAS.dll" successfully and the property functions are available in MATLAB.

Installing FluidLAB including LibIDGAS for 64-bit MATLAB®

This section describes the installation of both FluidLAB LibIDGAS.

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_LibIDGAS_x64.zip", you will see the folder

CD_FluidLAB_LibIDGAS

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 files:

FluidLAB_LibIDGAS_64.msi
FluidLAB_LibIDGAS_Docu_Eng.pdf
LibIDGAS.dll
Setup.exe

and folders

/vcredist_x64
/WindowsInstaller3_1.

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

Setup.exe.

Installation of FluidLAB LibIDGAS 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\LibIDGAS (for English version of Windows)
C:\Programme\FluidLAB\LibIDGAS (for German version of Windows)

By clicking the "Browse…" button, you can change the installation directory before installation (see Figure 2.2).

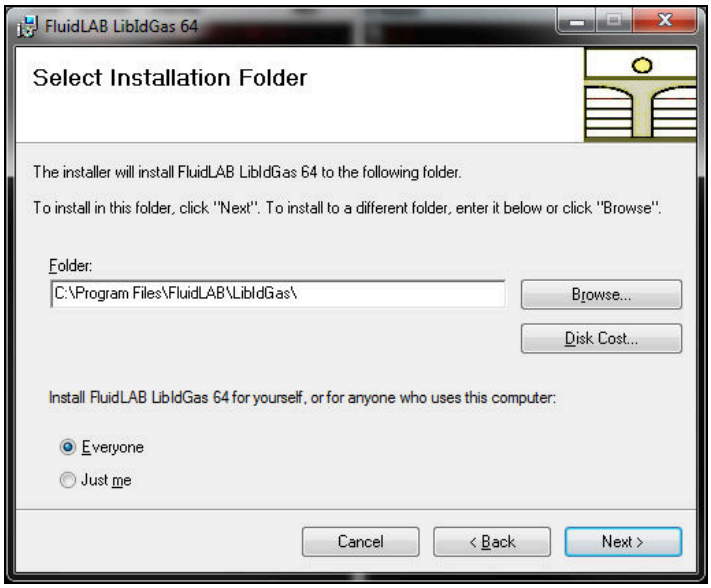

Figure 2.2: "Select Installation Folder"

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 LibIDGAS 64 has been successfully installed." Confirm this by clicking the "Close" button.

The installation program has copied the following files for LibIDGAS

capt_ico_big.ico	libifcoremd.dll
LC.dll	libiomp5md.dll
LibIDGAS.dll	libmmd.dll

into the directory

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

Now, you have to overwrite the file "LibIDGAS.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 "LibIDGAS.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\LibIDGAS (for English version of Windows)
C:\Programme\FluidLAB\LibIDGAS (for German version of Windows))

and insert the file "LibIDGAS.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 "LibIDGAS.dll" successfully and the property functions are available in MATLAB.

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

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

- Dynamic Link Library "LibIDGAS.dll" and other necessary system DLL files.

- MATLAB®-Interface-Programme for calculable functions

a_pt_id	Psi_igas_Xsi_id
cp_pt_id	R_id
cv_pt_id	Rho_pt_id
Eta_t_id	s_pt_id
h_pt_id	t_ph_id
Kappa_pt_id	t_ps_id
Lambda_t_id	t_pv_id
M_id	u_pt_id
Ny_pt_id	v_pt_id
p_ts_id	w_pt_id
p_tv_id	Xsi_igas_Psi_id
Pr_pt_id	

Please note that there is a difference in the file extension 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 LibIDGAS directory (the standard being

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

2.2 Licensing the LibIDGAS 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 LibIDGAS (see figure below).

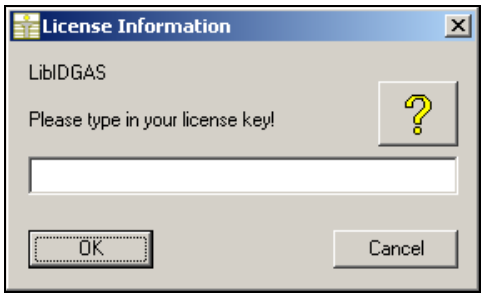

Figure 2.3: "License Information" window

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:

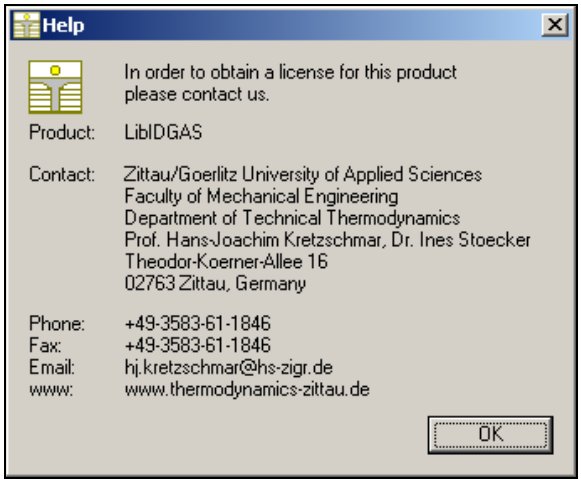

Figure 2.4: "Help" window

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

The "License Information" window will appear every time you use FluidLAB LibIDGAS until you enter a license code to complete registration. If you decide not to use FluidLAB LibIDGAS, you can uninstall the program following the instructions given in section 2.5 of this User's Guide.

2.3 Example: Calculating the Enthalpy $h = f(p,t,\xi_1 \ldots \xi_{10})$ of the Mixture of Gas in an M-File

Now we will calculate, step by step, the enthalpy h as a function of mixture pressure p, temperature t and a composition vector $\xi_1 \ldots \xi_{10}$ for ideal gas 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 a better view. Click the "Views" button and select "Details".
- Switch into the program directory of FluidLAB in which you will find the folder "\LibIDGAS"; in the standard case: "C:\Program Files\FluidLAB"
- Create the folder "\LibIDGAS_Example". Click "File", then click "New" in the pop-up menu and afterwards select "Folder". Name the new folder "\LibIDGAS_Example ".
- You will see the following window:

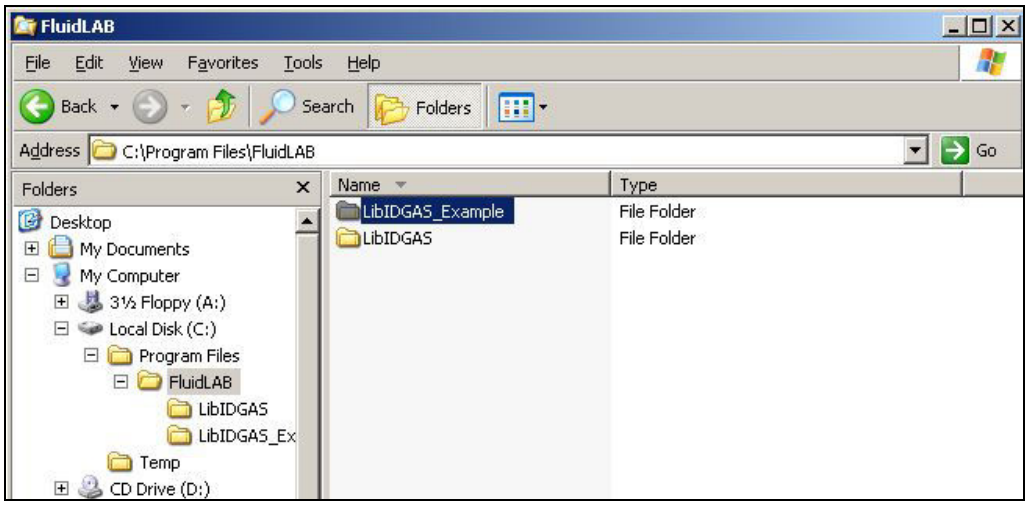

Figure 2.5: Folders "LibIDGAS" and "LibIDGAS_Example"

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

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

- You will see the following window:

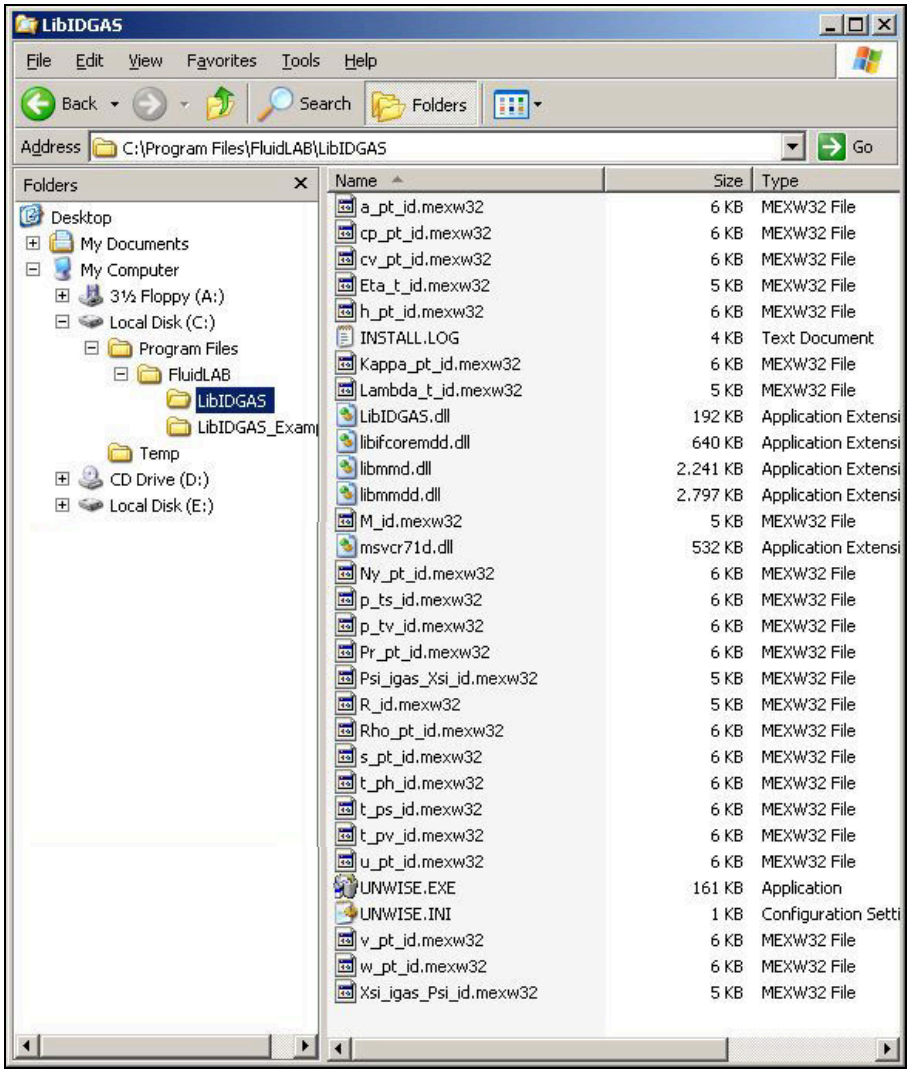

Figure 2.6: Contents of the folder "LibIDGAS"

You will now have to copy the necessary files following into the directory "C:\Program Files\FluidLAB\LibIDGAS_Example" in order to calculate the function $h = f(p,t,\xi_1 \ldots \xi_{10})$.

- The following files are necessary:
  - "h_pt_id.mexw32"
  - "LibIDGAS.dll"
  - "libifcoremdd.dll"
  - "libmmd.dll"
  - "libmmdd.dll"
  - "msvcr71d.dll"
- Click the file "h_pt_id.mexw32", then click "Edit" in the upper menu bar and select "Copy".
- Switch into the directory "C:\Program Files\FluidLAB\LibIDGAS_Example", click "Edit" and select "Paste".
- Repeat these steps in order to copy the other files listed above.

- You will see the following window:

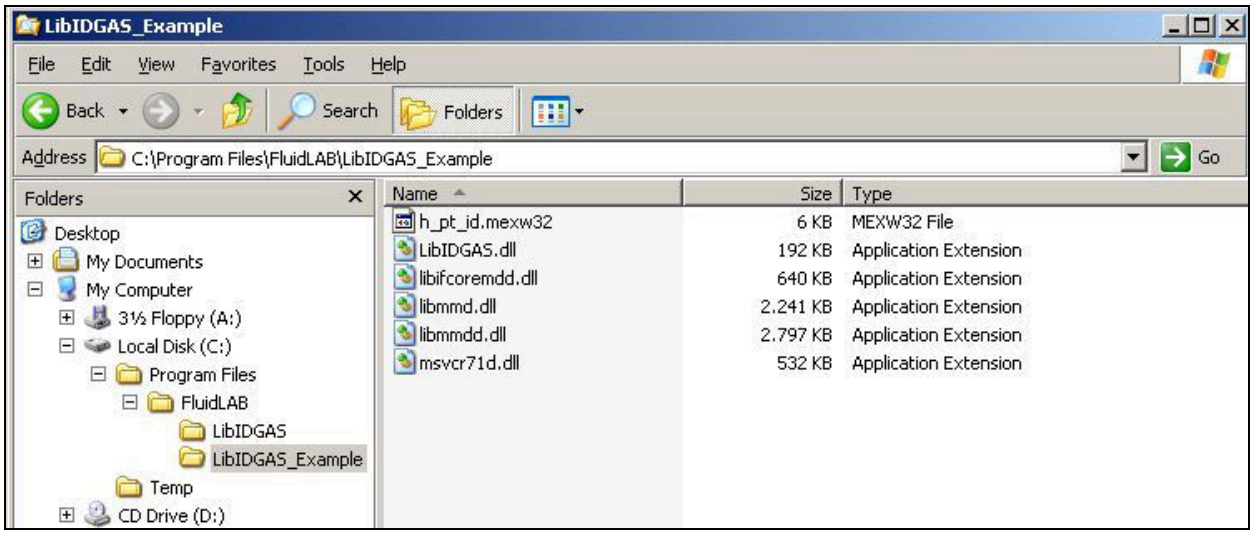

Figure 2.7: Contents of the folder "LibIDGAS_Example"

If you have installed the 64-bit version of LibIDGAS you will now have to copy the following files into the directory "C:\Program Files\FluidLAB\LibIDGAS_Example" in order to calculate the function $h = f(p,t,\xi_1 \ldots \xi_{10})$.

- The following six files are needed:
  - "h_pt_id.mexw64"
  - "LC.dll"
  - "LibIDGAS.dll"
  - "libifcoremd.dll"
  - "libiomp5.dll"
  - "libmmd.dll."
- Click the file "h_pt_id.mexw64", then click "Edit" in the upper menu bar and select "Copy."
- Switch into the directory "C:\Program Files\FluidLAB\LibIDGAS_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).
- Start MATLAB (if you did not start it before).
- Click the button marked in the following image in order to open the folder "\LibIDGAS_Example" in the window "Current Directory".

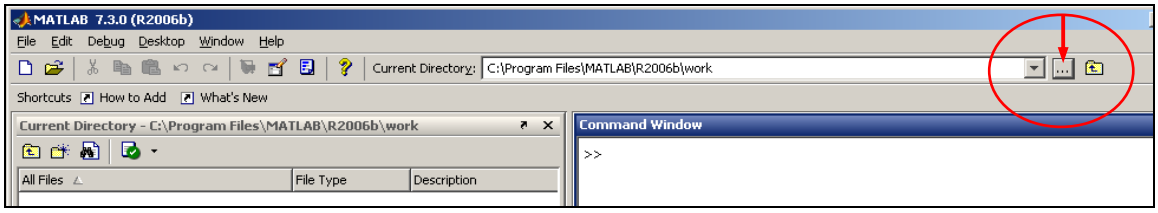

Figure 2.8: Selection of the working directory

- Search and click the directory "C:\Program Files\FluidLAB\LibIDGAS_Example" in the window which appears (see figure below).

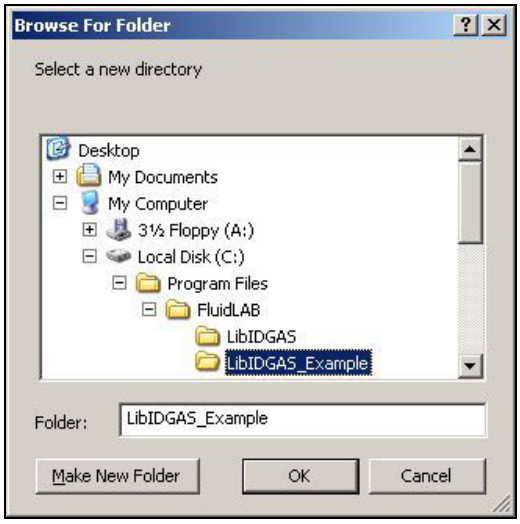

Figure 2.9: Choosing the "LibIDGAS_Example" folder

- Confirm your selection by clicking the "OK" button.
- First you need to create an M–File in MATLAB. Within MATLAB click "File", then select "New" and afterwards click "M-File".
- In case the "Editor" window appears as a separate window, you can embed it into MATLAB by clicking the arrow (see figure below) in order to obtain a better view.

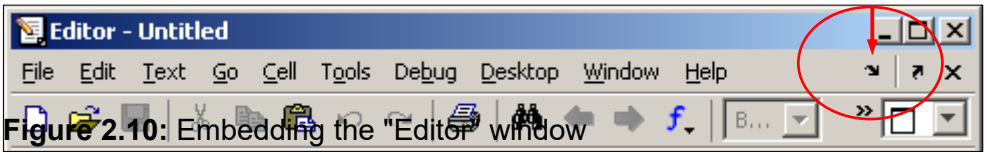

Figure 2.10: Embedding the "Editor" window

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

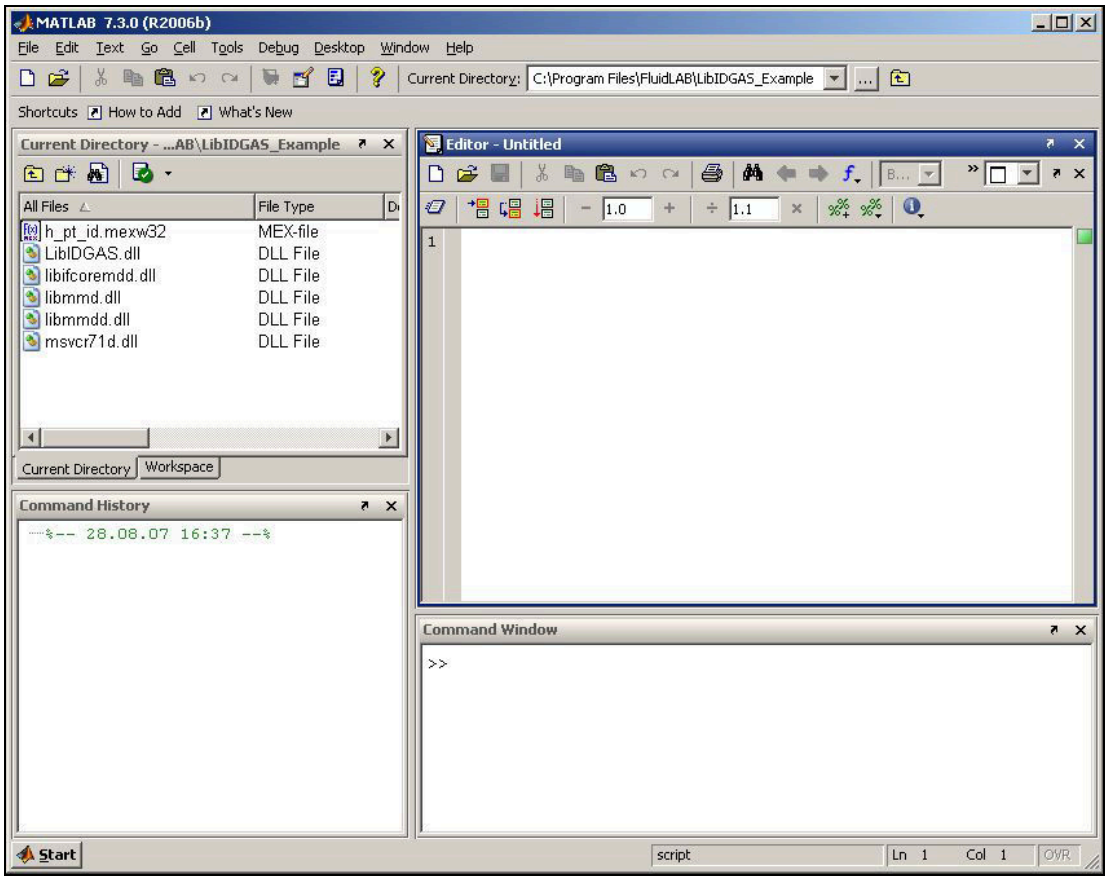

Figure 2.11: Embedded "Editor" window

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

Text to be written:	Explanation:
`% h_pt_id.m`	file name as comment
`%%`	paragraph separation
`p=1; % pressure in bar`	declaration of the variables pressure, temperature, art and composition of mixture
`t=100; % temperature in °C`	
`art=1; % input values in mass fractions`	
`Xi=[0 0 0 0 0 0.13 0.11 0 0 0.76] % composition`	
`%%`	paragraph separation
`h=h_pt_id(p,t,art,Xi)`	function call
`%%`	paragraph separation

- Remarks:
  - The program interprets the first line which starts with " % " to be a data description in "Current Directory"
  - Paragraph separations which are mandatory are being realised through " %% ". By this, declaration of variables and calculation instructions are also being separated.
  - The words which are printed in green, start with " % " and stand behind the variables are comments. In fact they are not necessary but they are reasonable for your overview and comprehensibility.
  - You have to leave out the semicolons behind the numerical values if you wish to see the result for *h* and the input parameters as well.

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

  - First operand: Value for p = 1 bar
    (Range of validity: p = 0.00001 bar ... 50 bar)
  - Second operand: Value for t = 100 °C
    (Range of validity: t = - 73.15 °C ... 3026.85 °C)
  - Third operand: Value for *art* = 1
    (Chose between: art = 1 for input in mass fractions $\xi_1 \ldots \xi_{10}$
    art = 0 for input in mole fractions, i.e. volume fractions $\psi_1 \ldots \psi_{10}$)
  - Fourth operand: Vector for the composition $\xi_1 \ldots \xi_{10}$ (see above).
- Save the "M-File" by clicking the "File" button and then click "Save As...".
- The menu "Save file as:" pops up; therein the folder name "LibIDGAS_Example" must be displayed next to "Save in:"
- Next to "File name" you have to type in "Example_h_pt_id_IDGAS.m" and then click the "Save" button.
- You will see the following window:

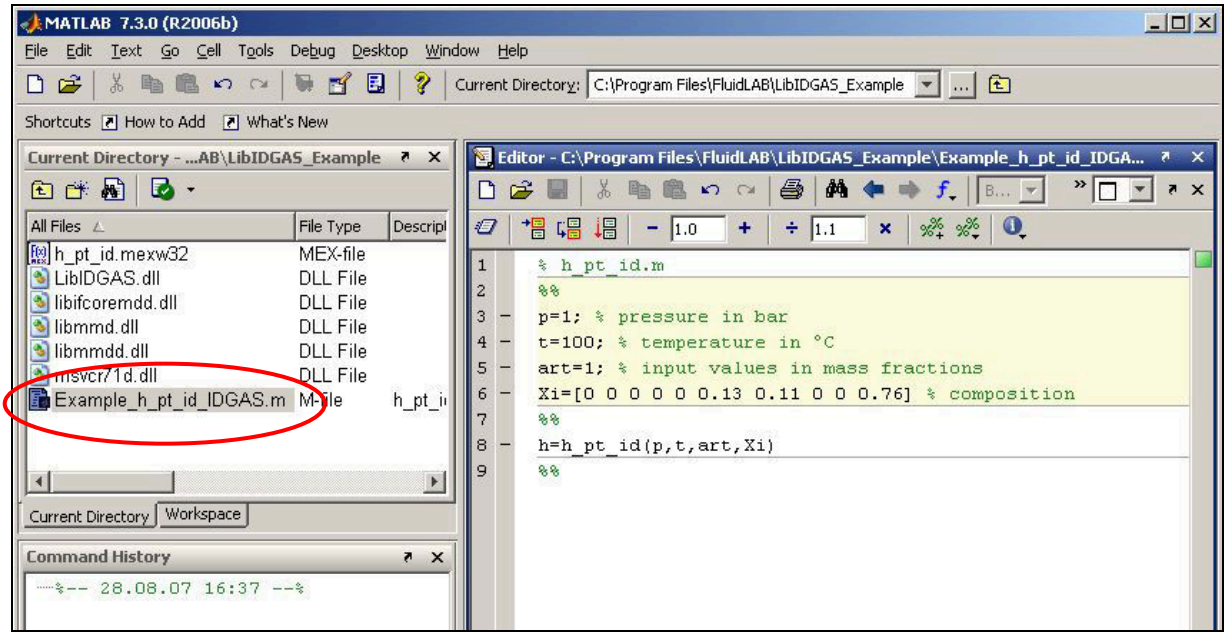

Figure 2.12: "Example_h_pt_id_IDGAS.m" M-file

- Within the window "Current Directory" the file "Example_h_pt_id_IDGAS.m" appears.
- Right-click this file and click "Run" in the menu which appears (see next figure).

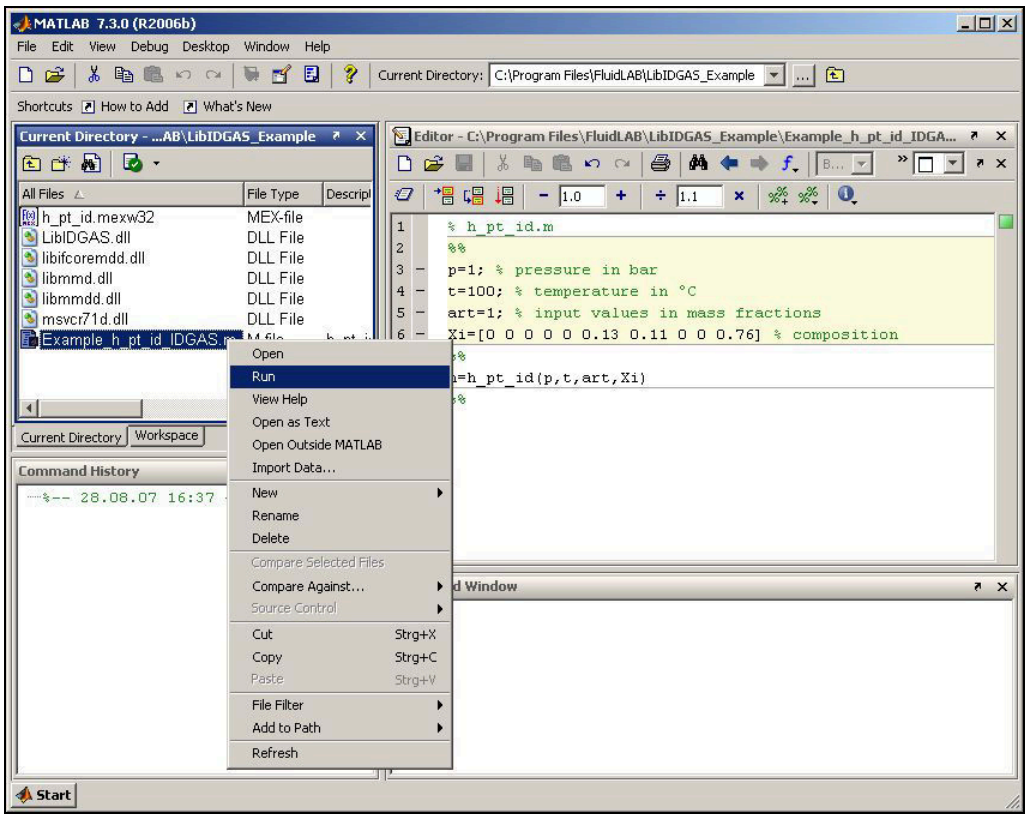

Figure 2.13: Running the "Example_h_pt_id_IDGAS.m" M-file

- You will see the following window:

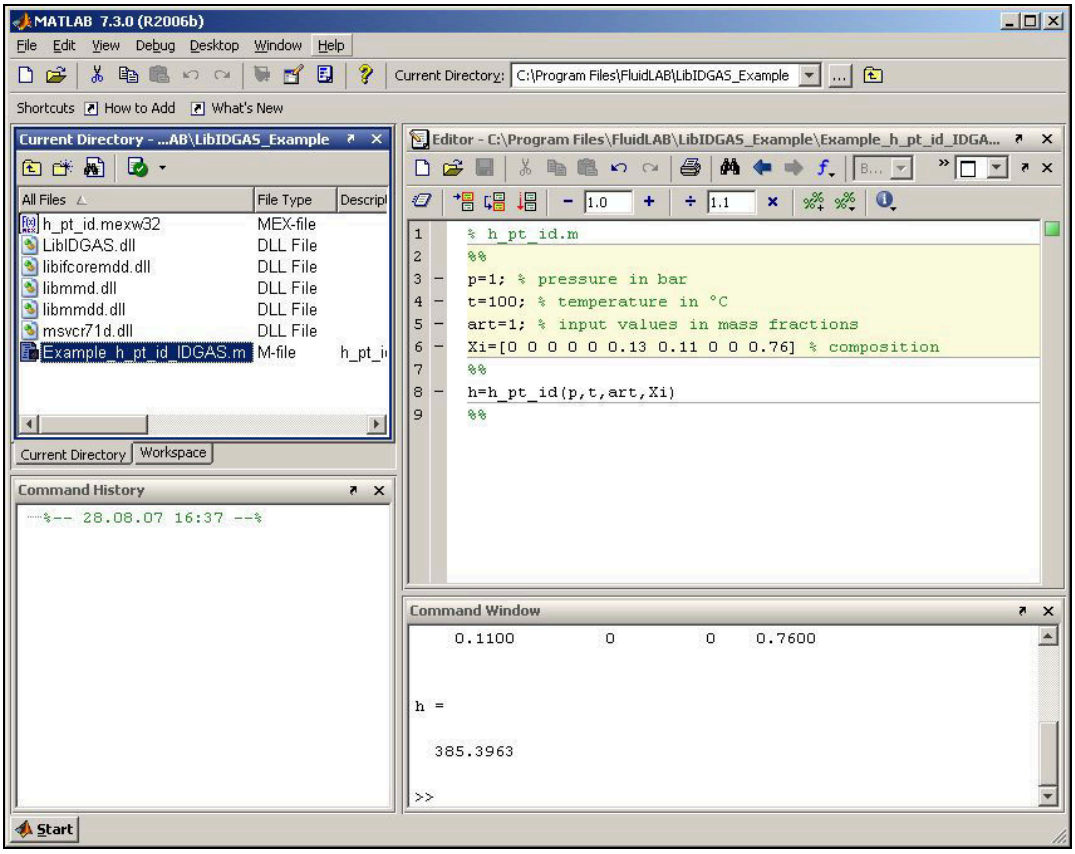

Figure 2.14: MATLAB® with calculated result

In the "Command Window" you will see the result "h = 385.3963". The corresponding unit is kJ/kg (cp. table of the property functions in Chapter 1).

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

2.4 Example: Calculating the Enthalpy $h = f(p,t,\xi_1 \ldots \xi_{10})$ of the Mixture of Gas in the Command Window

- Please follow the instructions from page 2/7 to 2/9.
- Start MATLAB (if you did not start it before).
- Click the button marked in the following image in order to open the folder "\LibIDGAS_Example" in the window "Current Directory.

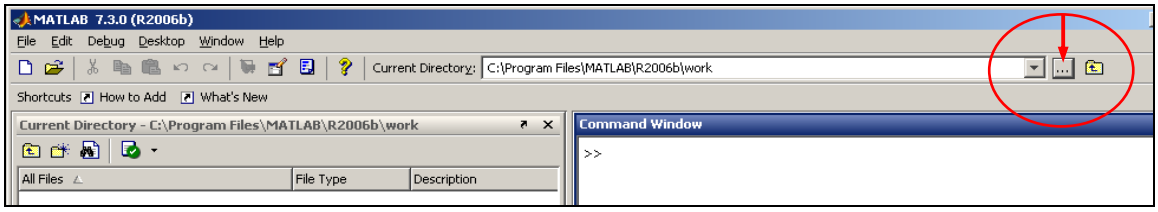

Figure 2.15: Selection of the working directory

- Search and click the directory "C:\Program Files\FluidLAB\LibIDGAS_Example" in the window which appears (see figure below).

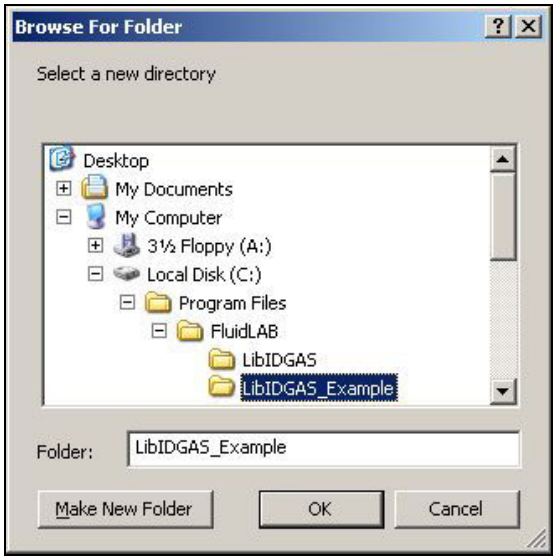

Figure 2.16: Choosing the "LibIDGAS_Example" folder

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

- You will see the following window:

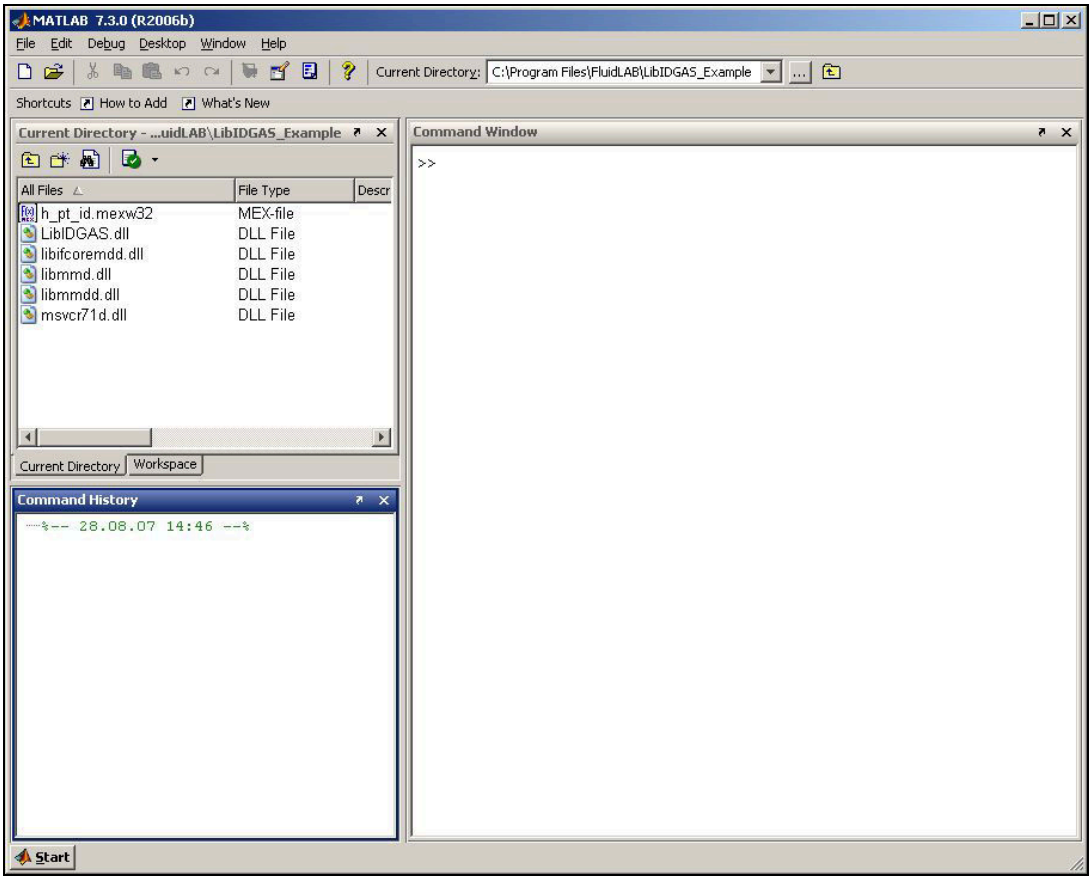

Figure 2.17: MATLAB® with necessary files

Corresponding to the table of property functions in Chapter 1 you have to call the function "h_pt_id" as follows for calculating $h = f(p,t,\xi_1 \ldots \xi_{10})$:

Enter the composition vector as follows:

Press "Space" between the single values. Decimal places are entered with dot.

- Type "Xi=[0 0 0 0 0 0.13 0.11 0 0 0.76]" and press the "ENTER" button.

In the following you can see the single values which the vector for the composition $\xi_1 \ldots \xi_{10}$ consists of:

ξ_1	for Argon	Ar	⇒ The value 0
ξ_2	for Neon	Ne	⇒ The value 0
ξ_3	for Nitrogen	N2	⇒ The value 0
ξ_4	for Oxygen	O2	⇒ The value 0
ξ_5	for Carbon monoxide	CO	⇒ The value 0
ξ_6	for Carbon dioxide	CO2	⇒ The value 0.13
ξ_7	for Steam	H2O	⇒ The value 0.11
ξ_8	for Sulfur dioxide	SO2	⇒ The value 0
ξ_9	for Air (dry)		⇒ The value 0
ξ_{10}	for Air specific nitrogen		⇒ The value 0.76

- Type "h=h_pt_id(1,100,1,Xi)" within the "Command Window".

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

  - First operand: Value for p = 1 bar
    (Range of validity: p = 0.00001 bar ... 50 bar)
  - Second operand: Value for t = 100 °C
    (Range of validity: t = - 73.15 °C ... 3026.85 °C)
  - Third operand: Value for *art* = 1
    (Chose between: art = 1 for input in mass fractions $\xi_1 \ldots \xi_{10}$
    art = 0 for input in mole fractions, i.e. volume fractions $\psi_1 \ldots \psi_{10}$)
  - Fourth operand: Vector for the composition $\xi_1 \ldots \xi_{10}$ (see above).

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

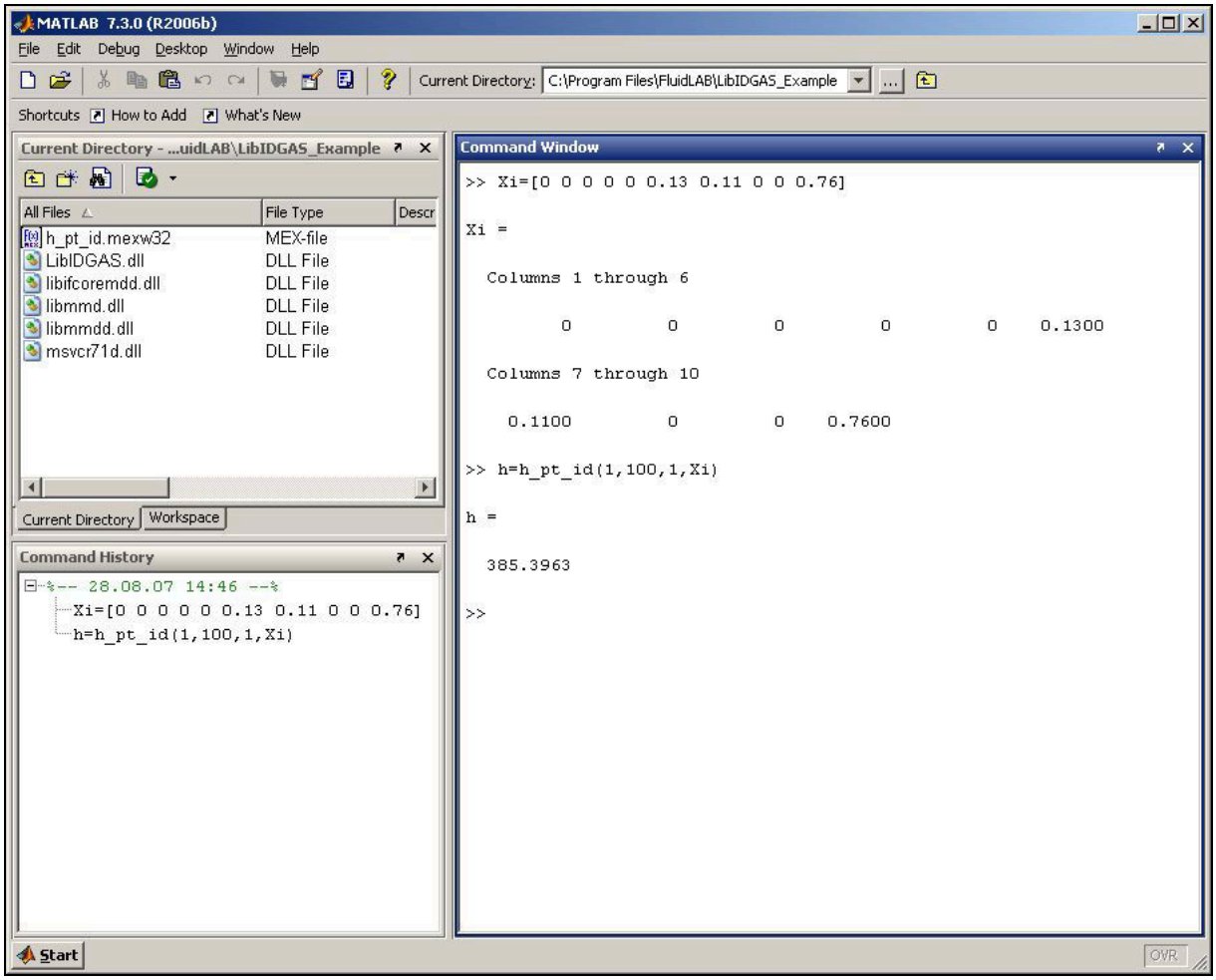

Figure 2.18: MATLAB® with calculated result

In the "Command Window" you will see the result "h = 385.3963". The corresponding unit is kJ/kg (cp. table of the property functions in Chapter 1).

To calculate other values, you have to copy the associated mexw32 or mexw64 files into the working directory as well because MATLAB can only call functions if they are located in the "Current Directory" window.

2.4 Using FluidLAB with SIMULINK

To use the functions of FluidLAB with the simulation program SIMULINK you have to start SIMULINK in MATLAB® by clicking on Simulink in the upper menu bar shown in Figure 2.19.

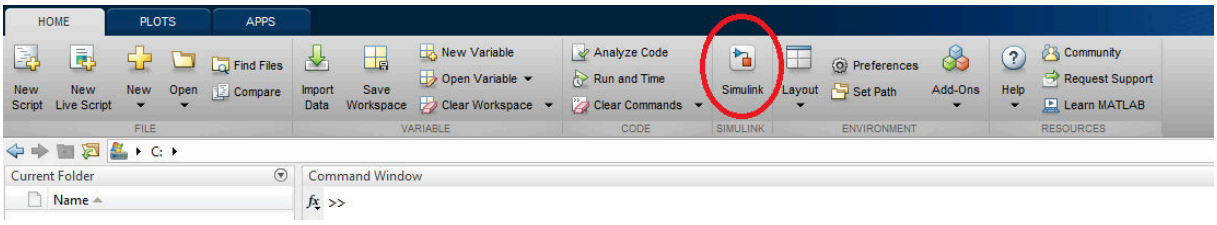

Figure 2.29: Starting Simulink

Then choose a blank model or a simulation in which you would like to use FluidLAB. Now you need to add a MATLAB function block that you can find in the library browser shown in Figure 2.20.

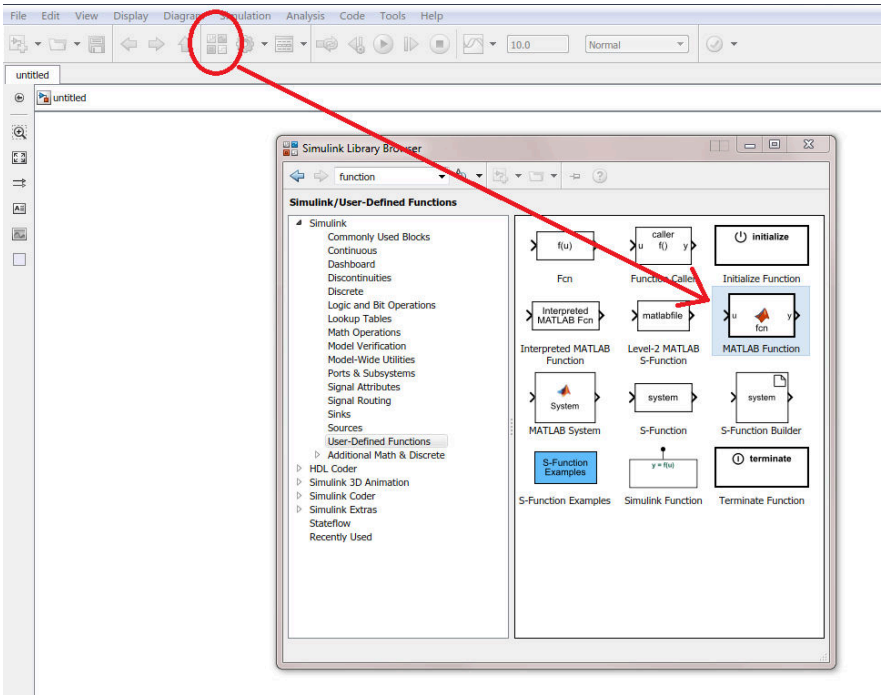

Figure 2.20: Simulink library browser and choosing a MATLAB Function

By dragging and dropping you can drag a Simulink block in your model. The function needs inputs and output that you can find in the Simulink library browser under sources and sinks. For this example constants were taken for the inputs and a display block were taken for outputting.

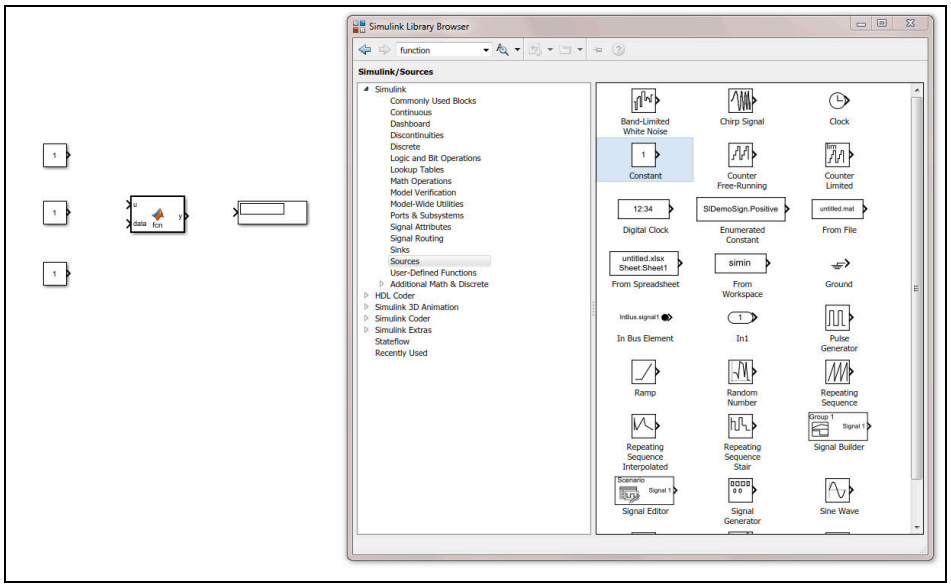

Figure 2.21: Inputs and outputs of the example

Now you have to link inputs and outputs to the MATLAB function block. By pressing and holding the left mouse button on the arrow of a block, you can draw a line and drag it to the MATLAB function block. With this method you can link all blocks together.

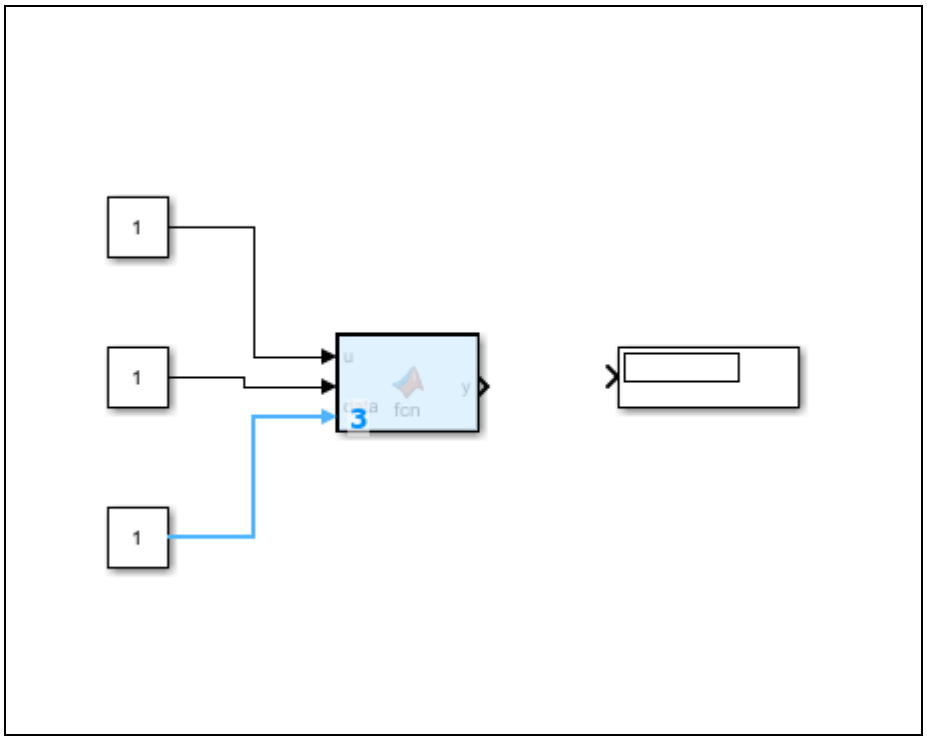

Figure 2.22: Linking blocks in Simulink

You can define the value of a constant block by double-click on them. If you want to calculate the example use the values you can find in section 2.3. With a double-click on the MATLAB function block you can define the function in MATLAB®. The following source code is for the example calculation and the table below describes the source code closer. You can adapt these few lines to call all other function of FluidLAB.

```
function h = fcn(p, t, x)
coder.extrinsic('addpath');
```

```
coder.extrinsic('h_pt_id');
addpath('C:\Program Files\FluidLAB\LibID');
h = h_pt_id(p,t,x);
```

Matlab source code	Explanation
`function h = fcn(p, t, x)`	function header, you can define the function name and the inputs like p, t and x of the example
`coder.extrinsic('addpath');`	necessary to add a path
`coder.extrinsic('h_pt_id');`	Choose the function name of the FluidLAB function
`addpath('C:\Program Files\FluidLAB\LibID');`	Add the installation path of FluidLAB
`h = h_pt_id(p,t,x);`	Linking the FluidLAB function to the MATLAB function block

You can copy and paste the sourcecode in MATLAB® or write it into the MATLAB® editor. The simulation will start by clicking the run button in Matlab or Simulink and you can see the example in the display block of the simulation which is shown in figure 2.23.

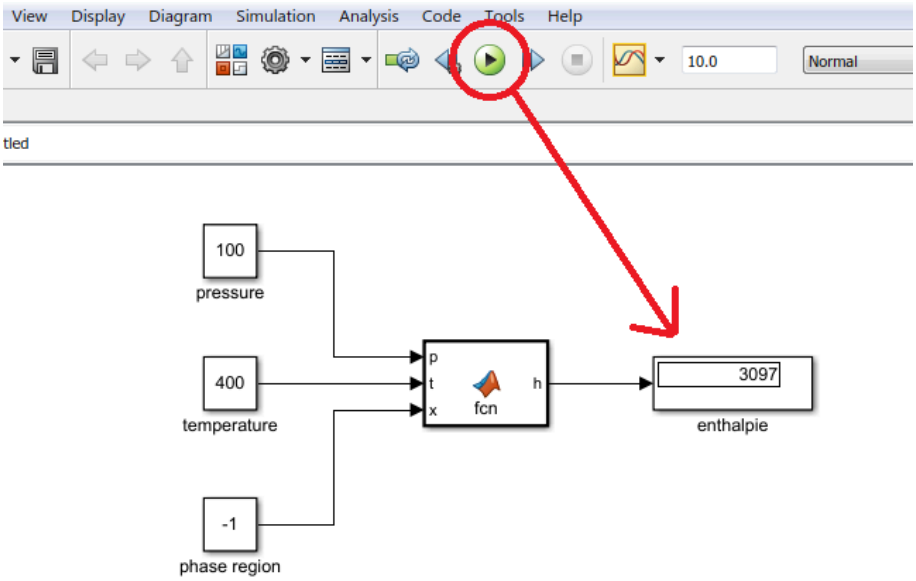

Figure 2.23: Starting the simulation and result of the calculation

Your result is may an other than shown in figure 2.23. If you want to calculate the example please use the values from section 2.3.

2.5 Removing LibIDGAS in FluidLAB

To remove the LibIDGAS 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 LibIDGAS" 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 LibIDGAS installed then the directory "FluidLAB" will be removed as well.

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 from the LibIDGAS calculation library.

2.1 Installing FluidLAB including LibIDGAS

This Section describes the installation of FluidLAB including the LibIDGAS property library. After you have downloaded and extracted the zip-file

CD_FluidLAB_LibIDGAS.zip (32 bit version)

or

CD_FluidLAB_LibIDGAS_x64.zip (64 bit version)

you will see the folder

CD_FluidLAB_LibIDGAS\ (32 bit version)

or

CD_FluidLAB_LibIDGAS_x64\ (64 bit version)

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

Open this folder by double-clicking on it.

In this folder you will see the following files:

FluidLAB_LibIDGAS_Setup.msi (for 32-bit installation)
FluidLAB_LibIDGAS_64_Setup.msi (for 64-bit installation)
FluidLAB_LibIDGAS_Docu_Eng.pdf
LibIDGAS.dll.
setup.exe

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

setup.exe.

If an error message from C++ appears, please double click the file

FluidLAB_LibIDGAS_Setup.msi (for 32-bit installation)

or

FluidLAB_LibIDGAS_64_Setup.msi (for 64-bit installation)

for the installation.

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

C:\Program Files (x86)\FluidLAB\LibIDGAS\ (for 32-bit installation)

or

C:\Program Files\FluidLAB\LibIDGAS\ (for 64-bit installation).

But, this offered path could cause problems with user rights and thus prevent the installation. Therefore, an example path

D:\Example\

is used in the following explanations, which is located on a drive that does not contain the Windows installation.

By clicking the "Browse…" button, you can change the installation directory before installation (see Figure 2.1).

Note:

The product name "Lib_ _ _ _ _" in the following Figures stands for the Library you are installing or have installed. In this case it is the LibIDGAS library.

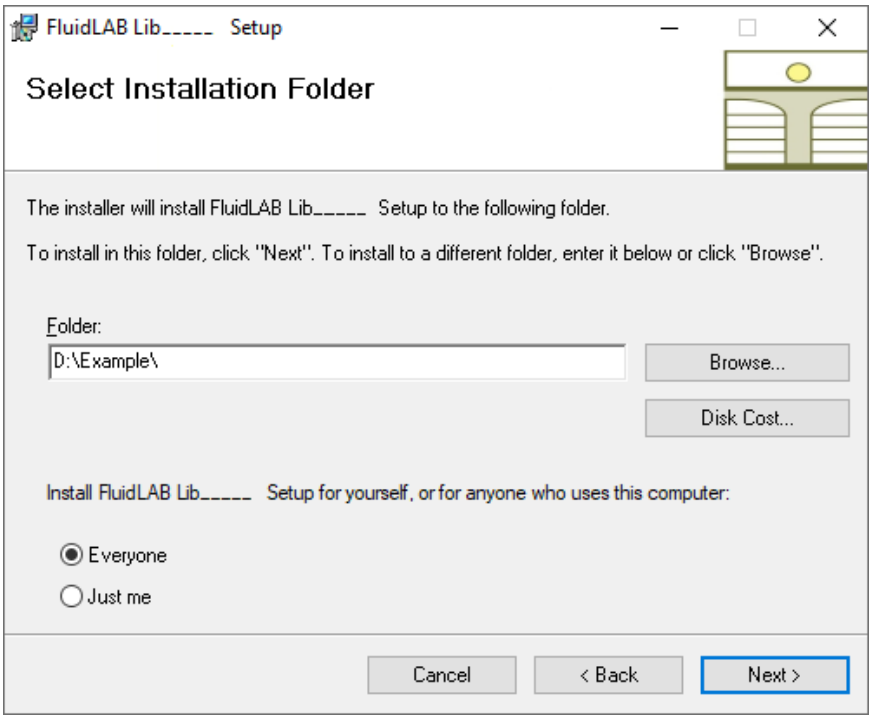

Figure 2.1: "Destination Location"

After you have chosen your desired installation path 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 into the chosen \LibIDGAS\ directory:

LibIDGAS.dll,

LC.dll,

libifcoremd.dll,

libiomp5md.dll,

Libmmd.dll.

In addition, there are specific files for all functions

*.mexw32 (for 32-bit version)

or

*.mexw64 (for 64-bit version).

The names of these functions are listed in Section 1.

Note:

To use the FluidLAB library LibIDGAS you can simply copy all delivered files into your MATLAB project folder or link the installation path to your project. How to add a path to your MATLAB project is described below in Section 2.4.

Now, you have to overwrite the file "LibIDGAS.dll" in your created \LibIDGAS\ directory with the file of the same name provided in the delivered CD. The directory is either

C:\Program Files (x86)\FluidLAB\LibIDGAS (for 32-bit installation)

or

C:\Program Files\FluidLAB\LibIDGAS (for 64-bit installation)

or the directory you have specified, e.g.

D:\Example\.

Now, the LibIDGAS property functions are available in MATLAB®.

2.2 Licensing the LibIDGAS 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 LibIDGAS (see Figure below).

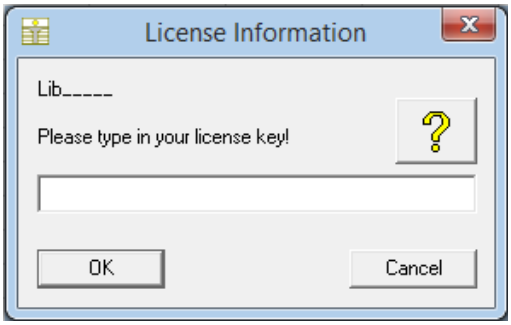

Figure 2.2: "License Information" window

Here you are asked to type in the license key. 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:

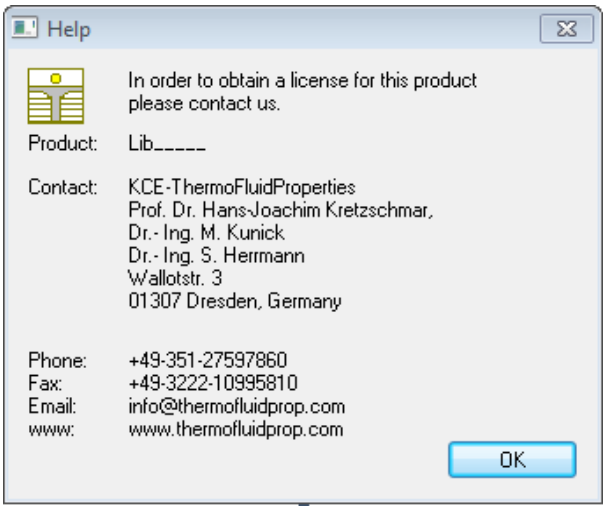

Figure 2.3: "Help" window

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

The "License Information" window will appear every time you use FluidLAB LibIDGAS until you enter a license code to complete registration. If you decide not to use FluidLAB LibIDGAS, you can uninstall the program following the instructions given in section 2.5 of this User's Guide.

2.3 Example Calculation

Now we will calculate, step by step, an example of a function to show how to use use FluidLAB mit the LibIDGAS library.

In the following we use the recommanded folder D:\Example\.

Note:

Of course, any other folder in which the LibIDGAS files are stored will also work, for example your current MATLAB® project directory.

Please carry out the following instructions:

- Start MATLAB® and choose your FluidLAB folder with the library LibIDGAS files in the upper directory bar of MATLAB® (shown in Figure 2.4, marked with 1).
- Now we create a new MATLAB® file to write our example calculation script. Click on the symbol shown in Figure 2.4, marked with 2.
- We have to save the file and give it a name. In our example we use “example.m” as the file name. To save click on the symbol shown in Figure 2.4, marked with 3.
- Type the following lines into the "example.m" window:
  The code is also shown in Figure 2.4, marked with 4.

Text to be written:	Explanation:
`% h_pt_id.m`	file name as comment
`%%`	paragraph separation
`p=1; % pressure in bar`	declaration of the variables pressure, temperature, art and composition of mixture
`t=100; % temperature in °C`	
`art=1; % input values in mass fractions`	
`Xi=[0 0 0 0 0 0.13 0.11 0 0 0.76] % composition`	
`%%`	paragraph separation
`h=h_pt_id(p,t,art,Xi)`	function call
`%%`	paragraph separation

- To calculate the example press F5 on your keyboard or click on the symbol shown in Figure 2.4, marked with 5.
- In the "Command Window" you will see the result "h = 385.3963", marked with 6 in Figure 2.4. The corresponding unit is kJ/kg (see table of the property functions in Chapter 1).

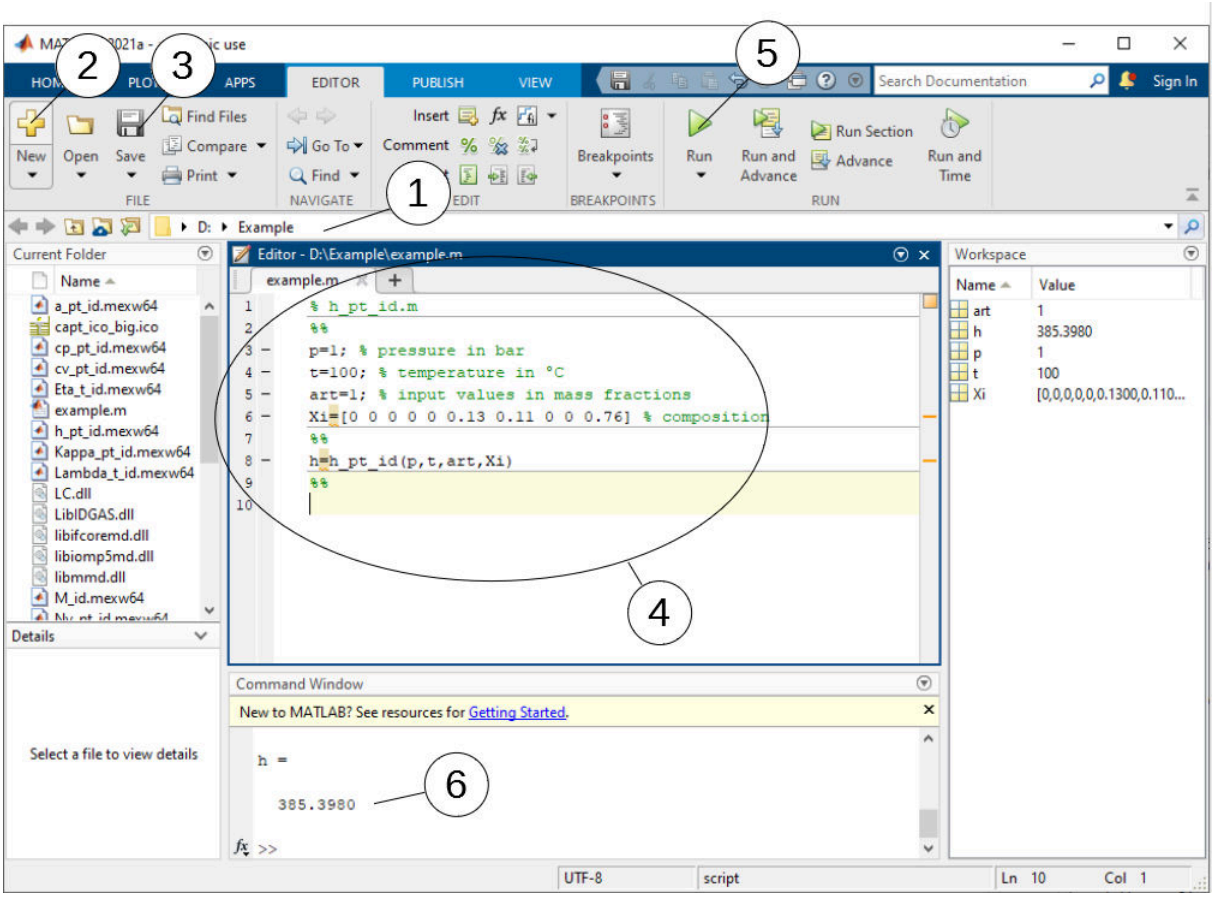

Figure 2.4: Example calculation in MATLAB®

- Remarks:

  - The program interprets the first line which starts with " % " to be a data description in "Current Directory"
  - Paragraph separations which are mandatory are being realised through " %%". By this, declaration of variables and calculation instructions are also being separated.
  - The words which are printed in green, start with " % " and stand behind the variables are comments. In fact they are not necessary but they are reasonable for your overview and comprehensibility.
  - You have to leave out the semicolons behind the numerical values if you wish to see the result for *h* and the input parameters as well.

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

- First operand: Value for p = 1 bar
  (Range of validity: p = 0.00001 bar ... 50 bar)
- Second operand: Value for t = 100 °C
  (Range of validity: t = - 73.15 °C ... 3026.85 °C)
- Third operand: Value for *art* = 1
  (Chose between: art = 1 for input in mass fractions $\xi_1 \ldots \xi_{10}$
  art = 0 for input in mole fractions, i.e. volume fractions $\psi_1 \ldots \psi_{10}$)
- Fourth operand: Vector for the composition $\xi_1 \ldots \xi_{10}$ (see above).

2.4 Using FluidLAB with SIMULINK

To use the functions of FluidLAB with the simulation program SIMULINK you have to start SIMULINK in MATLAB® by clicking on Simulink in the upper menu bar shown in Figure 2.5.

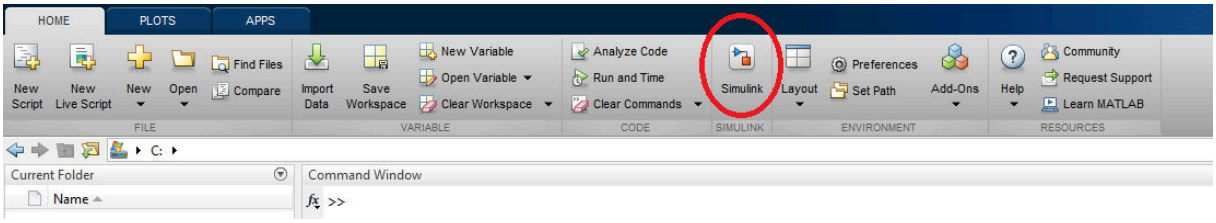

Figure 2.5: Starting Simulink

Then choose a blank model or a simulation in which you would like to use FluidLAB. Now you need to add a MATLAB function block that you can find in the library browser shown in Figure 2.6.

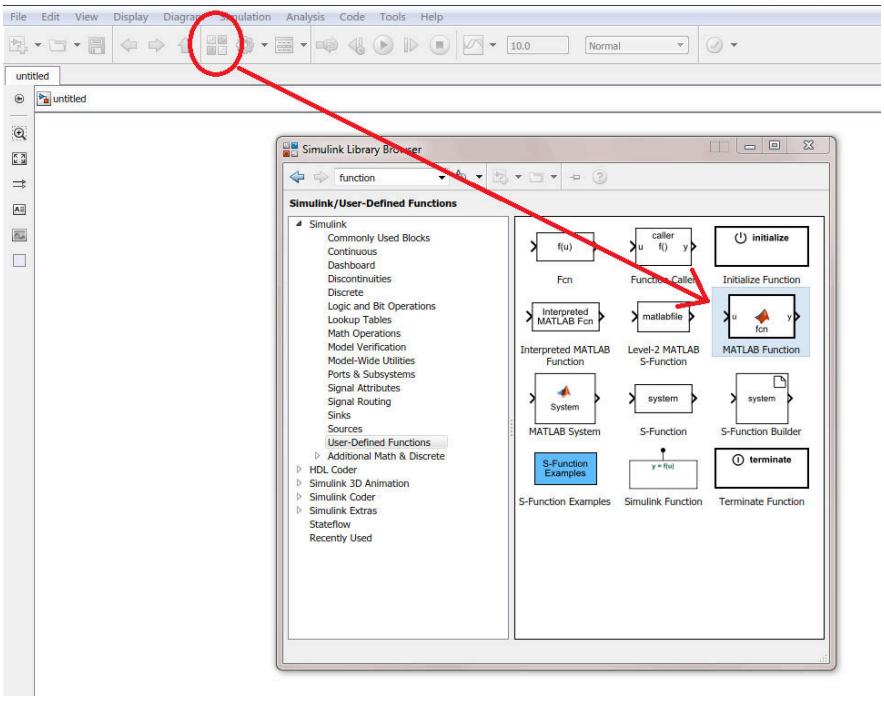

Figure 2.6: Simulink library browser and choosing a MATLAB Function

By dragging and dropping you can drag a Simulink block in your model. The function needs inputs and output that you can find in the Simulink library browser under sources and sinks. For this example constants were taken for the inputs and a display block were taken for outputting.

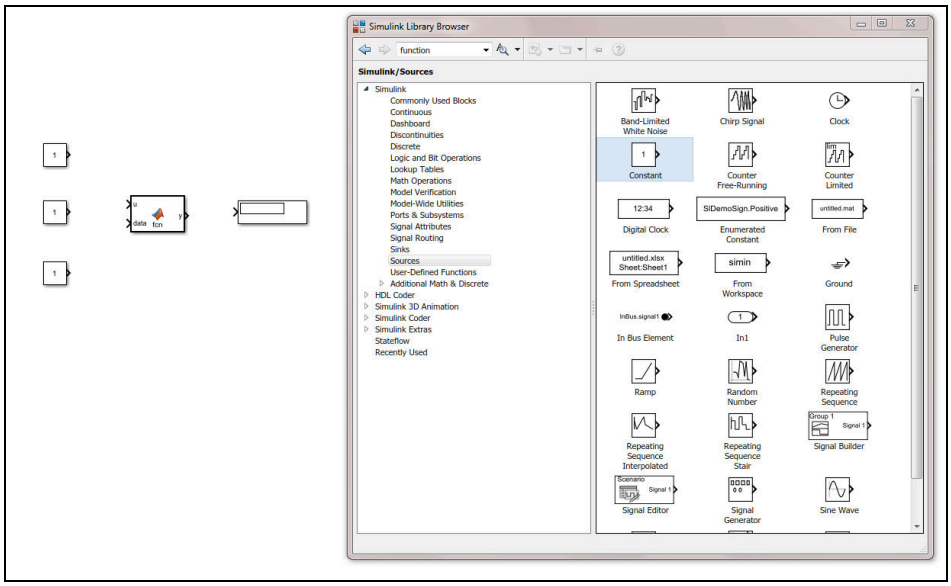

Figure 2.7: Inputs and outputs of the example

Now you have to link inputs and outputs to the MATLAB function block. By pressing and holding the left mouse button on the arrow of a block, you can draw a line and drag it to the MATLAB function block. With this method you can link all blocks together.

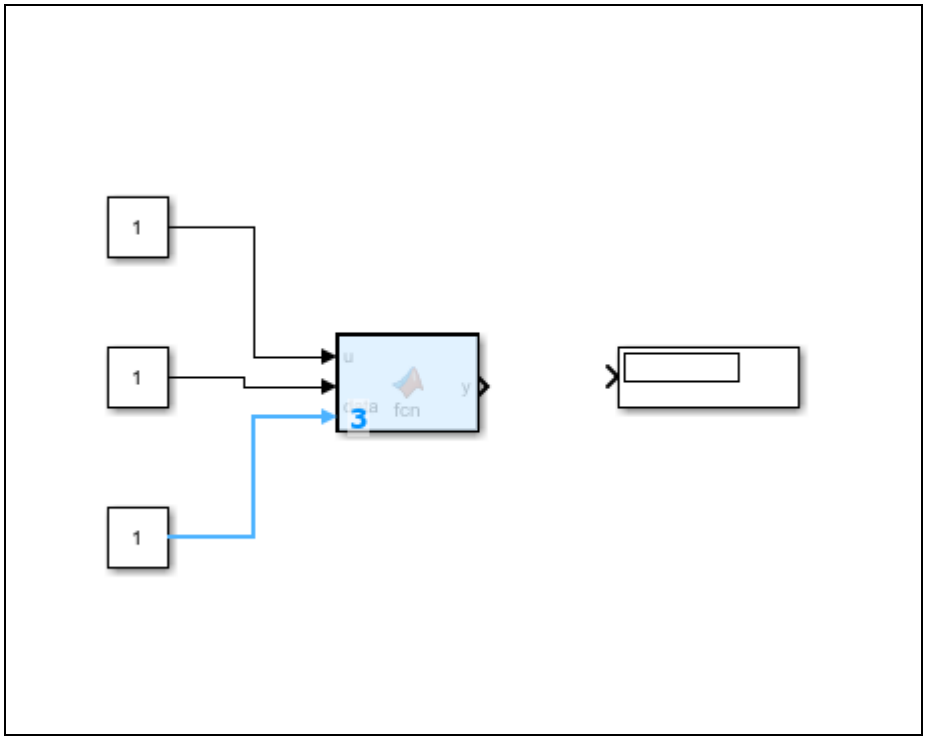

Figure 2.8: Linking blocks in Simulink

You can define the value of a constant block by double-click on them. If you want to calculate the example use the values you can find in Section 2.3. With a double-click on the MATLAB function block you can define the function in MATLAB®. The following source code is for the example calculation and the table below describes the source code closer.
You can adapt these few lines to call all other function of FluidLAB:

```
function h = fcn(p, t, x)
coder.extrinsic('addpath');
coder.extrinsic('h_pt_id');
addpath('D:\Example');
h = coder.nullcopy(zeros(size(1)));
h = h_pt_id(p,t,x);
```

Matlab source code	Explanation
`function h = fcn(p, t, x)`	function header, you can define the function name and the inputs like p, t and x of the example
`coder.extrinsic('addpath');`	necessary to add a path
`coder.extrinsic('h_pt_id');`	Choose the function name of the FluidLAB function
`addpath('D:\Example');`	Add the installation path of FluidLAB
`h = coder.nullcopy(zeros(size(1)));`	Declaration of the output value h and filling it with zeros
`h = h_pt_id(p,t,x);`	Linking the FluidLAB function to the MATLAB function block

Your can copy and paste the sourcecode in MATLAB® or write it into the MATLAB® editor. The simulation will start by clicking the run button in Matlab or Simulink and you can see the example in the display block of the simulation which is shown in Figure 2.23.

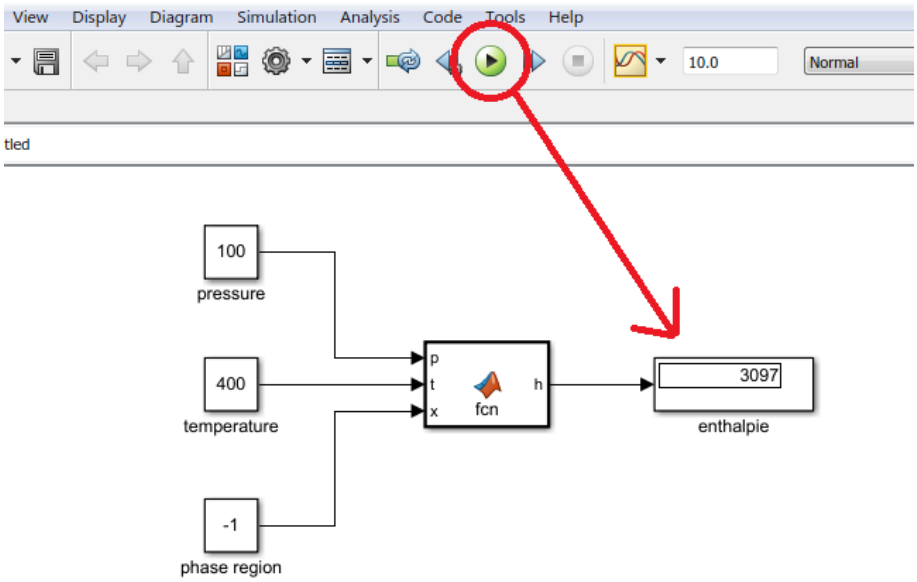

Figure 2.9: Starting the simulation and result of the calculation

Your result is may an other than shown in Figure 2.9. If you want to calculate the example please use the values from section 2.3.

2.5 Removing FluidLAB including LibIDGAS

- To remove the LibIDGAS 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 LibIDGAS" 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.

3 Program Documentation

Thermal Diffusivity $a = f(p,t,\xi_1...\xi_{10}$ or $\psi_1...\psi_{10})$

Function Name:	**a_pt_id**
Subprogram with value of the function: for the call out of Fortran	**REAL*8 FUNCTION A_PT_ID(P,T,ART, ZU)** REAL*8 P, T, COMP(0:10) INTEGER*4 ART
Subprogram with parameter: for the call out of the DLL	**INTEGER*4 FUNCTION C_A_PT_ID(A,P,T,ART, ZU)** REAL*8 A, P, T, ZU(0:10) INTEGER*4 C_APT_ID, ART

Input Values:

p	- Mixture pressure *p* in bar
t	- Temperature *t* in °C
type	= 1 for composition in mass fractions ξ = 0 for composition in mole fractions ψ
comp(1:10)	- Composition in mass fractions $\xi_1...\xi_{10}$ in kg/kg for type = 1 - Composition in mole fractions $\psi_1...\psi_{10}$ in kmol/kmol for type = 0

Result:

a_pt_id, a - Thermal diffusivity a in m^2/s

Range of Validity:

Mixture pressure *p*: from 0.01 mbar to 50 bar

Temperature *t* : from - 73.15 °C to 3026.85 °C

Comments:

Thermal diffusivity $a = \dfrac{\lambda}{\rho \cdot c_p}$

Results for wrong input values:

a_pt_id, a = -1

References:

Unsaturated and saturated humid air:

λ	corresponding to *Brandt* [15]
c_p	corresponding to VDI 4670 [21]
ρ	for ideal gas mixture

Specific Isobaric Heat Capacity c_p = f(p,t,ξ_1...ξ_{10} or ψ_1...ψ_{10})

Function Name: **cp_pt_id**

Subprogram with value of the function: for the call out of Fortran

```
REAL*8 FUNCTION CP_PT_ID(P,T,ART, COMP)
REAL*8  P, T, COMP(0:10)
INTEGER*4  ART
```

Subprogram with parameter: for the call out of the DLL

```
INTEGER*4 FUNCTION C_CP_PT_ID(CP,P,T,ART, COMP)
REAL*8  CP, P, T, COMP(0:10)
INTEGER*4 C_APT_ID, ART
```

Input Values:

p - Mixture pressure p in bar

t - Temperature t in °C

type =1 for composition in mass fractions ξ
=0 for composition in mole fractions ψ

comp(1:10) - Composition in mass fractions ξ_1...ξ_{10} in kg/kg for type = 1
- Composition in mole fractions ψ_1... ψ_{10} in kmol/kmol for type = 0

Result:

cp_pt_id, cp - Specific isobaric heat capacity in kJ/(kg K)

Range of Validity:

Mixture pressure p: from 0.01 mbar to 50 bar

Temperature t : from - 73.15 °C to 3026.85 °C

Comments:

Model of ideal mixture in consideration of dissociation above 500°C and $\psi_{H_2O} \geq 0.1$

Results for wrong input values:

cp_pt_id, cp = -1

References:

c_p corresponding to VDI 4670 [21]

Specific Isochoric Heat Capacity c_v = f(p,t,ξ_1...ξ_{10} or ψ_1...ψ_{10})

Function Name:	**cv_pt_id**
Subprogram with value of the function: for the call out of Fortran	**REAL*8 FUNCTION CV_PT_ID(P,T,ART, COMP)** REAL*8 P, T, COMP(0:10) INTEGER*4 ART
Subprogram with parameter: for the call out of the DLL	**INTEGER*4 FUNCTION C_CV_PT_ID(CV,P,T,ART, COMP)** REAL*8 CV, P, T, COMP(0:10) INTEGER*4 C_APT_ID, ART

Input Values:

p	- Mixture pressure p in bar
t	- Temperature t in °C
type	=1 for composition in mass fractions ξ =0 for composition in mole fractions ψ
comp(1:10)	- Composition in mass fractions ξ_1...ξ_{10} in kg/kg for type = 1 - Composition in mole fractions ψ_1... ψ_{10} in kmol/kmol for type = 0

Result:

cv_pt_id, cv - Specific isobaric heat capacity in kJ/(kg K)

Range of Validity:

Mixture pressure p: from 0.01 mbar to 50 bar

Temperature t : from - 73.15 °C to 3026.85 °C

Comments:

$c_v = c_p - R$

Results for wrong input values:

cv_pt_id, cv = -1

References:

Unsaturated and saturated humid air:

c_p corresponding to VDI 4670 [21]

Dynamic Viscosity η = f(t,ξ_1...ξ_{10} or ψ_1...ψ_{10})

Function Name: **Eta_t_id**

Subprogram with value of the function:
for the call out of Fortran

```
REAL*8 FUNCTION ETA_T_ID(P,T,ART, COMP)
REAL*8   T, COMP(0:10)
INTEGER*4  ART
```

Subprogram with parameter:
for the call out of the DLL

```
INTEGER*4 FUNCTION C_ETA_T_ID(ETA,T,ART, COMP)
REAL*8  ETA, T, COMP(0:10)
INTEGER*4 C_APT_ID, ART
```

Input Values:

t - Temperature t in °C

type =1 for composition in mass fractions ξ
=0 for composition in mole fractions ψ

comp(1:10) - Composition in mass fractions ξ_1...ξ_{10} in kg/kg for type = 1
- Composition in mole fractions ψ_1... ψ_{10} in kmol/kmol for type = 0

Result:

Eta_t_id, eta - Dynamic viscosity in Pa s

Range of Validity:

Temperature t : from - 73.15 °C to 3026.85 °C

Comments:

Calculation from *Brandt* - Model of ideal mixture

Results for wrong input values:

Eta_t_id, Eta = -1

References:

Unsaturated and saturated humid air:

η corresponding to *Brandt* [15]

Specific Enthalpy $h = f(p,t,\xi_1...\xi_{10}$ or $\psi_1...\psi_{10})$

Function Name: **h_pt_id**

Subprogram with value of the function:
for the call out of Fortran

```
REAL*8 FUNCTION H_PT_ID(P,T,ART, COMP)
REAL*8  P, T, COMP(0:10)
INTEGER*4  ART
```

Subprogram with parameter:
for the call out of the DLL

```
INTEGER*4 FUNCTION C_H_PT_ID(H,P,T,ART, COMP)
REAL*8  H, P, T, COMP(0:10)
INTEGER*4 C_APT_ID, ART
```

Input Values:

p - Mixture pressure *p* in bar

t - Temperature *t* in °C

type =1 for composition in mass fractions ξ
=0 for composition in mole fractions ψ

comp(1:10) - Composition in mass fractions $\xi_1...\xi_{10}$ in kg/kg for type = 1
- Composition in mole fractions $\psi_1...\ \psi_{10}$ in kmol/kmol for type = 0

Result:

h_pt_id, h - Specific enthalpy in kJ/kg

Range of Validity:

Mixture pressure *p*: from 0.01 mbar to 50 bar

Temperature *t* : from - 73.15 °C to 3026.85 °C

Comments:

Model of ideal mixture in consideration of dissociation above 500 °C and $\psi_{H_2O} \geq 0.1$

Results for wrong input values:

h_pt_id, h = -1000

References:

h corresponding to VDI 4670 [21]

Isentropic Exponent κ = f(p,t,ξ_1...ξ_{10} or ψ_1...ψ_{10})

Function Name: **Kappa_pt_id**

Subprogram with value of the function: **REAL*8 FUNCTION KAPPA_PT_ID(P,T,ART, COMP)**
for the call out of Fortran
REAL*8 P, T, COMP(0:10)
INTEGER*4 ART

Subprogram with parameter: **INTEGER*4 FUNCTION**
for the call out of the DLL **C_KAPPA_PT_ID(KAPPA,P,T,ART,COMP)**
REAL*8 KAPPA, P, T, COMP(0:10)
INTEGER*4 C_APT_ID, ART

Input Values:

p - Mixture pressure *p* in bar

t - Temperature *t* in °C

type =1 for composition in mass fractions ξ
=0 for composition in mole fractions ψ

comp(1:10) - Composition in mass fractions ξ_1...ξ_{10} in kg/kg for type = 1
- Composition in mole fractions ψ_1... ψ_{10} in kmol/kmol for type = 0

Result:

Kappa _pt_id, Kappa - Isentropic exponent

Range of Validity:

Mixture pressure *p*: from 0.01 mbar to 50 bar

Temperature *t* : from - 73.15 °C to 3026.85 °C

Comments:

Kappa $\kappa = \dfrac{c_p}{c_p - R}$

Results for wrong input values:

Kappa_pt_id, Kappa = -1

References:

Unsaturated and saturated humid air:

c_p corresponding to VDI 4670 [21]

Thermal Conductivity λ = f(t,ξ_1...ξ_{10} or ψ_1...ψ_{10})

Function Name: **Lambda_t_id**

Subprogram with value of the function: **REAL*8 FUNCTION LAMBDA_T_ID(T,ART, COMP)**
for the call out of Fortran REAL*8 T, COMP(0:10)
INTEGER*4 ART

Subprogram with parameter: **INTEGER*4 FUNCTION C_LAMBDA_T_ID(LAMBDA,T,ART,ZU)**
for the call out of the DLL REAL*8 LAMBDA, T, COMP(0:10)
INTEGER*4 C_APT_ID, ART

Input Values:

t - Temperature *t* in °C

type =1 for composition in mass fractions ξ
=0 for composition in mole fractions ψ

comp(1:10) - Composition in mass fractions ξ_1...ξ_{10} in kg/kg for type = 1
- Composition in mole fractions ψ_1... ψ_{10} in kmol/kmol for type = 0

Result:

Lambda_t_id, Lambda - Thermal conductivity in W/(m K)

Range of Validity:

Temperature *t* : from - 73.15 °C to 3026.85 °C

Comments:

Calculation from *Brandt* - Model of ideal mixture

Results for wrong input values:

Lambda_t_id, Lambda = -1

References:

Unsaturated and saturated humid air:

λ corresponding to *Brandt* [15]

Molar Mass M = f($\xi_1 ... \xi_{10}$ or $\psi_1 ... \psi_{10}$)

Function Name:	**M_id**
Subprogram with value of the function: for the call out of Fortran	**REAL*8 FUNCTION M_ID(ART, COMP)** REAL*8 COMP(0:10) INTEGER*4 ART
Subprogram with parameter: for the call out of the DLL	**INTEGER*4 FUNCTION C_M_ID(M,ART, COMP)** REAL*8 M, COMP(0:10) INTEGER*4 C_APT_ID, ART

Input Values:

type =1 for composition in mass fractions ξ
=0 for composition in mole fractions ψ

comp(1:10) - Composition in mass fractions $\xi_1 ... \xi_{10}$ in kg/kg for type = 1
- Composition in mole fractions $\psi_1 ... \psi_{10}$ in kmol/kmol for type = 0

Result:

M_id, M - Molar mass in kg/kmol

Comments:

Calculation from *Blanke*

Results for wrong input values:

M_id, M = -1

References:

M corresponding to *Blanke* [20]

Kinematic Viscosity ν = f(p,t,ξ_1...ξ_{10} or ψ_1...ψ_{10})

Function Name: **Ny_pt_id**

Subprogram with value of the function: for the call out of Fortran

```
REAL*8 FUNCTION NY_PT_ID(P,T,ART, COMP)
REAL*8  P, T, COMP(0:10)
INTEGER*4  ART
```

Subprogram with parameter: for the call out of the DLL

```
INTEGER*4 FUNCTION C_NY_PT_ID(CV,P,T,ART, COMP)
REAL*8  NY, P, T, COMP(0:10)
INTEGER*4 C_APT_ID, ART
```

Input Values:

p - Mixture pressure *p* in bar

t - Temperature *t* in °C

type =1 for composition in mass fractions ξ
=0 for composition in mole fractions ψ

comp(1:10) - Composition in mass fractions ξ_1...ξ_{10} in kg/kg for type = 1
- Composition in mole fractions ψ_1... ψ_{10} in kmol/kmol for type = 0

Result:

Ny_pt_id, Nue - Kinematic viscosity in m^2/s

Range of Validity:

Mixture pressure *p*: from 0.01 mbar to 50 bar

Temperature *t* : from – 73.15 °C to 3026.85 °C

Comments:

Kinematic viscosity

Results for wrong input values:

Ny_pt_id, Ny = -1

References:

Unsaturated and saturated humid air:

η corresponding to *Brandt* [15]

ρ for ideal gas mixture

Backward Function: Pressure $p = f(t,s,\xi_1...\xi_{10}$ or $\psi_1...\psi_{10})$

Function Name: **p_ts_id**

Subprogram with value of the function:
for the call out of Fortran

```
REAL*8 FUNCTION P_TS_ID(T,S,ART, COMP)
REAL*8 T, S, COMP(0:10)
INTEGER*4  ART
```

Subprogram with parameter:
for the call out of the DLL

```
INTEGER*4 FUNCTION C_P_TS_ID(P,T,S,ART, COMP)
REAL*8  P, T, S, COMP(0:10)
INTEGER*4 C_APT_ID, ART
```

Input Values:

t - Temperature *t* in °C

s - Specific Entropy in kJ/(kg K)

type =1 for composition in mass fractions ξ
=0 for composition in mole fractions ψ

comp(1:10) - Composition in mass fractions $\xi_1...\xi_{10}$ in kg/kg for type = 1
- Composition in mole fractions $\psi_1...\ \psi_{10}$ in kmol/kmol for type = 0

Result:

p_ts_id, p - Mixture pressure in bar

Range of Validity:

Temperature *t* : from – 73.15 °C to 3026.85 °C

Entropy *s*: from – 2.3771 kJ/(kg K) to 9.7061 kJ/(kg K)

Comments:

- Model of ideal mixture in consideration of dissociation above 500 °C
- Iteration of *p* from *s* = f(*p*,*t*,(1:10))

Results for wrong input values:

p_ts_id, p = -1

References:

s corresponding to VDI 4670 [21]

Backward Function: Pressure $p = f(t, v, \xi_1 ... \xi_{10}$ or $\psi_1 ... \psi_{10})$

Function Name:	**p_tv_id**
Subprogram with value of the function: for the call out of Fortran	**REAL*8 FUNCTION P_TV_ID(T,V,ART, COMP)** REAL*8 T, V, COMP(0:10) INTEGER*4 ART
Subprogram with parameter: for the call out of the DLL	**INTEGER*4 FUNCTION C_P_TV_ID(P,T,V,ART, COMP)** REAL*8 P, T, V, COMP(0:10) INTEGER*4 C_APT_ID, ART

Input Values:

v	- Specific volume v in m³/kg
t	- Temperature t in °C
type	=1 for composition in mass fractions ξ =0 for composition in mole fractions ψ
comp(1:10)	- Composition in mass fractions $\xi_1 ... \xi_{10}$ in kg/kg for type = 1 - Composition in mole fractions $\psi_1 ... \psi_{10}$ in kmol/kmol for type = 0

Result:

p_tv_id , v - Mixture pressure in bar

Range of Validity:

Temperature t :	from – 73.15 °C to 3026.85 °C
Specific volume v:	from 5.1 m^3/kg to 2.9 109 m^3/kg

Comments:

$$p = \frac{R \cdot T}{v}$$

Results for wrong input values:

p_tv_id, p = -1

PRANDTL-Number Pr = f(p,t,ξ_1...ξ_{10} or ψ_1...ψ_{10})

Function Name: **Pr_pt_id**

Subprogram with value of the function: for the call out of Fortran

```
REAL*8 FUNCTION PR_PT_ID(P,T,ART, COMP)
REAL*8  P, T, COMP(0:10)
INTEGER*4  ART
```

Subprogram with parameter: for the call out of the DLL

```
INTEGER*4 FUNCTION C_PR_PT_ID(PR,P,T,ART, COMP)
REAL*8  PR, P, T, COMP(0:10)
INTEGER*4 C_APT_ID, ART
```

Input Values:

p - Mixture pressure p in bar

t - Temperature t in °C

type =1 for composition in mass fractions ξ
=0 for composition in mole fractions ψ

comp(1:10) - Composition in mass fractions ξ_1...ξ_{10} in kg/kg for type = 1
- Composition in mole fractions ψ_1... ψ_{10} in kmol/kmol for type = 0

Result:

Pr_pt_id, Pr - PRANDTL-Number

Range of Validity:

Temperature t: from – 73.15 °C to 3026.85 °C

Mixture pressure p: from 0.01 mbar to 50 bar

Comments:

PRANDTL-number

Results for wrong input values:

Pr_pt_id, Pr = -1

References:

Unsaturated and saturated humid air:

λ corresponding to *Brandt* [15]

η corresponding to *Brandt* [15]

c_p corresponding to VDI 4670 [21]

Mole Fraction ψ_i = f(i,ξ_1...ξ_{10})

Function Name: **Psi_igas_Xsi_id**

Subprogram with value of the function:
for the call out of Fortran

```
REAL*8 FUNCTION PSI_IGAS_ID(IGAS, COMP)
REAL*8  IGAS, COMP(0:10)
INTEGER*4  ART
```

Subprogram with parameter:
for the call out of the DLL

```
INTEGER*4 FUNCTION C_PSI_IGAS_ID(PSI,IGAS, COMP)
REAL*8  PSI, IGAS, COMP(0:10)
INTEGER*4 C_APT_ID, ART
```

Input Values:

i - Gas number

comp(1:10) - Composition in mass fractions ξ_1...ξ_{10} in kg/kg for type = 1

Result:

Psi_igas_Xsi_id, Psi - Mole fraction in kmol/kmol

Comments:

Calculation: $\psi_i = \frac{R_i}{\sum(\xi_i \cdot R_i)} \cdot \xi_i$

Results for wrong input values:

Psi_igas_Xsi_id, Psi = -1

Specific Gas Constant R = f($\xi_1 ... \xi_{10}$ or $\psi_1 ... \psi_{10}$)

Function Name: **R_id**

Subprogram with value of the function:
for the call out of Fortran

```
REAL*8 FUNCTION R_ID(ART, COMP)
REAL*8  COMP(0:10)
INTEGER*4  ART
```

Subprogram with parameter:
for the call out of the DLL

```
INTEGER*4 FUNCTION C_R_ID(R,ART, COMP)
REAL*8  R, COMP(0:10)
INTEGER*4 C_APT_ID, ART
```

Input Values:

type =1 for composition in mass fractions ξ
=0 for composition in mole fractions ψ

comp(1:10) - Composition in mass fractions $\xi_1 ... \xi_{10}$ in kg/kg for type = 1
- Composition in mole fractions $\psi_1 ... \psi_{10}$ in kmol/kmol for type = 0

Result:

R_id, R - Specific gas constant in kJ/(kg K)

Comments:

Calculation: $R = \sum_i (\xi_i \cdot R_i)$

$$R = \frac{1}{\sum_i (\frac{\psi_i}{R_i})}$$

Results for wrong input values:

R_id, R = -1

Density ρ = f(p,t,ξ_1...ξ_{10} or ψ_1...ψ_{10})

Function Name: **Rho_pt_id**

Subprogram with value of the function: **REAL*8 FUNCTION RHO_PT_ID(P,T,ART, COMP)**
for the call out of Fortran
```
REAL*8  P, T, COMP(0:10)
INTEGER*4  ART
```

Subprogram with parameter: **INTEGER*4 FUNCTION C_RHO_PT_ID(RHO,P,T,ART,COMP)**
for the call out of the DLL
```
REAL*8  RHO, P, T, COMP(0:10)
INTEGER*4 C_APT_ID, ART
```

Input Values:

p	- Mixture pressure *p* in bar
t	- Temperature *t* in °C
type	=1 for composition in mass fractions ξ =0 for composition in mole fractions ψ
comp(1:10)	- Composition in mass fractions ξ_1...ξ_{10} in kg/kg for type = 1 - Composition in mole fractions ψ_1... ψ_{10} in kmol/kmol for type = 0

Result:

Rho_pt_id, Rho - Density in kg/m^3

Range of Validity:

Mixture pressure *p*: from 0.01 mbar to 50 bar

Temperature *t* : from - 73.15 °C to 3026.85 °C

Comments:

Calculation : $\rho = \dfrac{p}{R \cdot T}$

Results for wrong input values:

Rho_pt_id, Rho = -1

Specific Entropy $s = f(p,t,\xi_1...\xi_{10}$ or $\psi_1...\psi_{10})$

Function Name: **s_pt_id**

Subprogram with value of the function:
for the call out of Fortran

```
REAL*8 FUNCTION S_PT_ID(P,T,ART, COMP)
REAL*8  P, T, COMP(0:10)
INTEGER*4  ART
```

Subprogram with parameter:
for the call out of the DLL

```
INTEGER*4 FUNCTION C_S_PT_ID(S,P,T,ART, COMP)
REAL*8  S, P, T, COMP(0:10)
INTEGER*4 C_APT_ID, ART
```

Input Values:

p - Mixture pressure *p* in bar

t - Temperature *t* in °C

type =1 for composition in mass fractions ξ
=0 for composition in mole fractions ψ

comp(1:10) - Composition in mass fractions $\xi_1...\xi_{10}$ in kg/kg for type = 1
- Composition in mole fractions $\psi_1...\ \psi_{10}$ in kmol/kmol for type = 0

Result:

s_pt_id, s - Specific entropy in kJ/(kg K)

Range of Validity:

Mixture pressure *p*: from 0.01 mbar to 50 bar

Temperature *t* : from - 73.15 °C to 3026.85 °C

Comments:

Model of ideal mixture in consideration of dissociation above 500 °C and $\psi_{H_2O} \geq 0.1$

Results for wrong input values:

s_pt_id, s = -1000

References:

s corresponding to VDI 4670 [21]

Backward Function: Temperature t = f(p,h,ξ_1...ξ_{10} or ψ_1...ψ_{10})

Function Name:	**t_ph_id**
Subprogram with value of the function: for the call out of Fortran	**REAL*8 FUNCTION T_PH_ID(P,H,ART, COMP)** REAL*8 P, H, COMP(0:10) INTEGER*4 ART
Subprogram with parameter: for the call out of the DLL	**INTEGER*4 FUNCTION C_T_PH_ID(T,P,H,ART, COMP)** REAL*8 T, P, H, COMP(0:10) INTEGER*4 C_APT_ID, ART

Input Values:

p	- Mixture pressure p in bar
h	- Enthalpy h in kJ/kg
type	=1 for composition in mass fractions ξ =0 for composition in mole fractions ψ
comp(1:10)	- Composition in mass fractions ξ_1...ξ_{10} in kg/kg for type = 1 - Composition in mole fractions ψ_1... ψ_{10} in kmol/kmol for type = 0

Result:

t_ph_id, t - Temperature in °C

Range of Validity:

Mixture pressure p:	from 0.01 mbar to 50 bar
Enthalpy h:	from –135.6 kJ/kg to 4100 kJ/kg

Comments:

Iteration of t from h = f (p, t, (1:10))

Results for wrong input values:

t_ph_id, t = -1000

References:

h corresponding to VDI 4670 [21]

Backward Function: Temperature t = f(p,s,ξ_1...ξ_{10} or ψ_1...ψ_{10})

Function Name: **t_ps_id**

Subprogram with value of the function: for the call out of Fortran

```
REAL*8 FUNCTION T_PS_ID(P,S,ART, COMP)
REAL*8  P, S, COMP(0:10)
INTEGER*4  ART
```

Subprogram with parameter: for the call out of the DLL

```
INTEGER*4 FUNCTION C_T_PS_ID(T,P,S,ART, COMP)
REAL*8  T, P, S, COMP(0:10)
INTEGER*4 C_APT_ID, ART
```

Input Values:

p - Mixture pressure p in bar

s - Entropy s in kJ/(kg K)

type =1 for composition in mass fractions ξ
=0 for composition in mole fractions ψ

comp(1:10) - Composition in mass fractions ξ_1...ξ_{10} in kg/kg for type = 1
- Composition in mole fractions ψ_1... ψ_{10} in kmol/kmol for type = 0

Result:

t_ps_id, t - Temperature in °C

Range of Validity:

Mixture pressure p: from 0.001 bar to 50 bar

Enthalpy s: from –2.377 kJ/(kg K) to 9.706 kJ/(kg K)

Comments:

Iteration of t from s = f (p,t,(1:10))

Results for wrong input values:

t_ps_id, t = -1000

References:

s corresponding to VDI 4670 [21]

Backward Function: Temperature t = f(p,v,ξ_1...ξ_{10} or ψ_1...ψ_{10})

Function Name: **t_pv_id**

Subprogram with value of the function: for the call out of Fortran

```
REAL*8 FUNCTION T_PV_ID(P,V,ART, COMP)
REAL*8  P, V, COMP(0:10)
INTEGER*4  ART
```

Subprogram with parameter: for the call out of the DLL

```
INTEGER*4 FUNCTION C_T_PV_ID(T,P,V,ART, COMP)
REAL*8  T, P, V, COMP(0:10)
INTEGER*4 C_APT_ID, ART
```

Input Values:

p - Mixture pressure p in bar

v - Specific volume v in m^3/kg

type =1 for composition in mass fractions ξ
=0 for composition in mole fractions ψ

comp(1:10) - Composition in mass fractions ξ_1...ξ_{10} in kg/kg for type = 1
- Composition in mole fractions ψ_1... ψ_{10} in kmol/kmol for type = 0

Result:

t_pv_id, t - Temperature in °C

Range of Validity:

Mixture pressure p: from 0.01 mbar to 50 bar

Specific volume v: from 5.1 m^3/kg to 2.9 109 m^3/kg

Comments:

Calculation: $T = \frac{p \cdot v}{R}$

Results for wrong input values:

t_pv_id, t = -1000

Specific Internal Energy u = f(p,t,ξ_1...ξ_{10} or ψ_1...ψ_{10})

Function Name: **u_pt_id**

Subprogram with value of the function: for the call out of Fortran

```
REAL*8 FUNCTION U_PT_ID(P,T,ART, COMP)
REAL*8  P, T, COMP(0:10)
INTEGER*4  ART
```

Subprogram with parameter: for the call out of the DLL

```
INTEGER*4 FUNCTION C_U_PT_ID(U,P,T,ART, COMP)
REAL*8  U, P, T, COMP(0:10)
INTEGER*4 C_APT_ID, ART
```

Input Values:

p - Mixture pressure p in bar

t - Temperature t in °C

type =1 for composition in mass fractions ξ
=0 for composition in mole fractions ψ

comp(1:10) - Composition in mass fractions ξ_1...ξ_{10} in kg/kg for type = 1
- Composition in mole fractions ψ_1... ψ_{10} in kmol/kmol for type = 0

Result:

u_pt_id, u - Specific internal energy in kJ/kg

Range of Validity:

Mixture pressure p: from 0.01 mbar to 50 bar

Temperature t : from –73.15 °C to 3026.85 °C

Comments:

Calculation: u = h(p, t, (1:10)) - R · T

Results for wrong input values:

u_pt_id, u = -1000

References:

h corresponding to VDI 4670 [21]

Specific Volume v = f(p,t,ξ_1...ξ_{10} or ψ_1...ψ_{10})

Function Name:	**v_pt_id**
Subprogram with value of the function: for the call out of Fortran	**REAL*8 FUNCTION V_PT_ID(P,T,ART, COMP)** REAL*8 P, T, COMP(0:10) INTEGER*4 ART
Subprogram with parameter: for the call out of the DLL	**INTEGER*4 FUNCTION C_V_PT_ID(V,P,T,ART, COMP)** REAL*8 V, P, T, COMP(0:10) INTEGER*4 C_APT_ID, ART

Input Values:

p	- Mixture pressure p in bar
t	- Temperature t in °C
type	=1 for composition in mass fractions ξ =0 for composition in mole fractions ψ
comp(1:10)	- Composition in mass fractions ξ_1...ξ_{10} in kg/kg for type = 1 - Composition in mole fractions ψ_1... ψ_{10} in kmol/kmol for type = 0

Result:

v_pt_id, v - Specific volume in m^3/kg

Range of Validity:

Mixture pressure p:	from 0.01 mbar to 50 bar
Temperature t :	from –73.15 °C to 3026.85 °C

Comments:

Calculation : $v = \frac{R_m \cdot T}{p}$

Results for wrong input values:

v_pt_id, v = -1

Isentropic Speed of Sound w = f(p,t,ξ_1...ξ_{10} or ψ_1...ψ_{10})

Function Name: **w_pt_id**

Subprogram with value of the function: for the call out of Fortran

```
REAL*8 FUNCTION W_PT_ID(P,T,ART, COMP)
REAL*8  P, T, COMP(0:10)
INTEGER*4  ART
```

Subprogram with parameter: for the call out of the DLL

```
INTEGER*4 FUNCTION C_W_PT_ID(W,P,T,ART, COMP)
REAL*8  W, P, T, COMP(0:10)
INTEGER*4 C_APT_ID, ART
```

Input Values:

p - Mixture pressure p in bar

t - Temperature t in °C

type =1 for composition in mass fractions ξ
=0 for composition in mole fractions ψ

comp(1:10) - Composition in mass fractions ξ_1...ξ_{10} in kg/kg for type = 1
- Composition in mole fractions ψ_1... ψ_{10} in kmol/kmol for type = 0

Result:

w_pt_id , w - Isentropic speed of sound in m/s

Range of Validity:

Mixture pressure p: from 0.01 mbar to 50 bar

Temperature t : from –73.15 °C to 3026.85 °C

Comments:

Calculation : $w = \sqrt{\dfrac{R_m \cdot T \cdot c_p}{c_p - R_m}}$

c_p = f(p, t, (1:10))

Results for wrong input values:

w_pt_id, w = -1

References:

c_p corresponding to VDI 4670 [21]

Mass Fraction ξ_i = f($i, \psi_1 ... \psi_{10}$)

Function Name: **Xsi_igas_Psi_id**

Subprogram with value of the function:
for the call out of Fortran

```
REAL*8 FUNCTION XSI_IGAS_ID(IGAS, COMP)
REAL*8  IGAS, COMP(0:10)
INTEGER*4  ART
```

Subprogram with parameter:
for the call out of the DLL

```
INTEGER*4 FUNCTION C_XSI_IGAS_ID(XSI,IGAS, COMP)
REAL*8  XSI, IGAS, COMP(0:10)
INTEGER*4 C_APT_ID, ART
```

Input Values:

i - Gas number

comp(1:10) - Composition in mole fractions $\psi_1 ... \psi_{10}$ in kmol/kmol for type = 0

Result:

Xsi_igas_Psi_id, Xsi - Mass fraction in kg/kg

Comments:

Calculation: $\xi_i = \frac{M_i}{\sum(\psi_i \cdot M_i)} \cdot \psi_i$

Results for wrong input values:

Xsi_igas_Psi_id, Xsi = -1

KCE

KCE-ThermoFluidProperties
www.thermofluidprop.com

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

Water and Steam

Library LibIF97

- Industrial Formulation IAPWS-IF97 (Revision 2007)
- Supplementary Standards
  - IAPWS-IF97-S01
  - IAPWS-IF97-S03rev
  - IAPWS-IF97-S04
  - IAPWS-IF97-S05
- IAPWS Revised Advisory Note No. 3 on Thermodynamic Derivatives (2008)

Library LibSBTL_IF97
Library LibSBTL_95

Extremely fast property calculations according to the IAPWS Guideline 2015
Spline-based Table Look-up Method (SBTL)
applied to the
Industrial Formulation IAPWS-IF97
and to the
Scientific Formulation IAPWS-95
for Computational Fluid Dynamics and simulating non-stationary processes

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:

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

and of the ideal gases:
SO_2, CO, Ne
(Scientific Formulation of Bücker et al.)

Consideration of:

- Dissociation from VDI 4670
- Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:

- Dry air from Lemmon et al.
- Steam, water and ice from IAPWS-IF97 and IAPWS-06

Consideration of:

- Condensation and freezing of steam
- Dissociation from VDI 4670
- Poynting effect from ASHRAE RP-1485

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

Ar	NO	He	Propylene
Ne	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

Humid Air

Library ASHRAE LibHuAirProp

Model: Virial equation from ASHRAE Report RP-1485 for real mixture of the real fluids:
- Dry air
- Steam

Consideration of:

- Enhancement of the partial saturation pressure of water vapor at elevated total pressures

www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bücker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bücker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

Helmholtz energy equation for the mixing term

(also useable for calculating the Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

$C_2H_6O_2$	Ethylene glycol
$C_3H_8O_2$	Propylene glycol
C_2H_5OH	Ethanol
CH_3OH	Methanol
$C_3H_8O_3$	Glycerol
K_2CO_3	Potassium carbonate
$CaCl_2$	Calcium chloride
$MgCl_2$	Magnesium chloride
NaCl	Sodium chloride
$C_2H_3KO_2$	Potassium acetate
$CHKO_2$	Potassium formate
LiCl	Lithium chloride
NH_3	Ammonia

Formulation of the International Institute of Refrigeration (IIR 2010)

Ethanol
Library LibC2H5OH
Formulation of Schroeder (2012)

Methanol
Library LibCH3OH
Formulation of de Reuck and Craven (1993)

Propane
Library LibPropane
Formulation of Lemmon et al. (2009)

Siloxanes as ORC Working Fluids

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

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

Tetradecamethylhexasiloxane $C_{14}H_{42}O_5Si_6$ **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)

Nitrogen and Oxygen
Libraries LibN2 and LibO2
Formulations of Span et al. (2000) and Schmidt and Wagner (1985)

Hydrogen
Library LibH2
Formulation of Leachman et al. (2009)

Helium
Library LibHe
Formulation of Arp et al. (1998)

Hydrocarbons

Decane $C_{10}H_{22}$ **Library LibC10H22**
Isopentane C_5H_{12} **Library LibC5H12_ISO**
Neopentane C_5H_{12} **Library LibC5H12_NEO**
Isohexane C_6H_{14} **Library LibC6H14**
Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

Carbon monoxide **CO** **Library LibCO**
Carbonyl sulfide **COS** **Library LibCOS**
Hydrogen sulfide H_2S **Library LibH2S**
Nitrous oxide N_2O **Library LibN2O**
Sulfur dioxide SO_2 **Library LibSO2**
Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

For more information please contact:

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Professor Hans-Joachim Kretzschmar

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01307 Dresden, Germany

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Phone: +49-351-27597860
Mobile: +49-172-7914607
Fax: +49-3222-4262250

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.

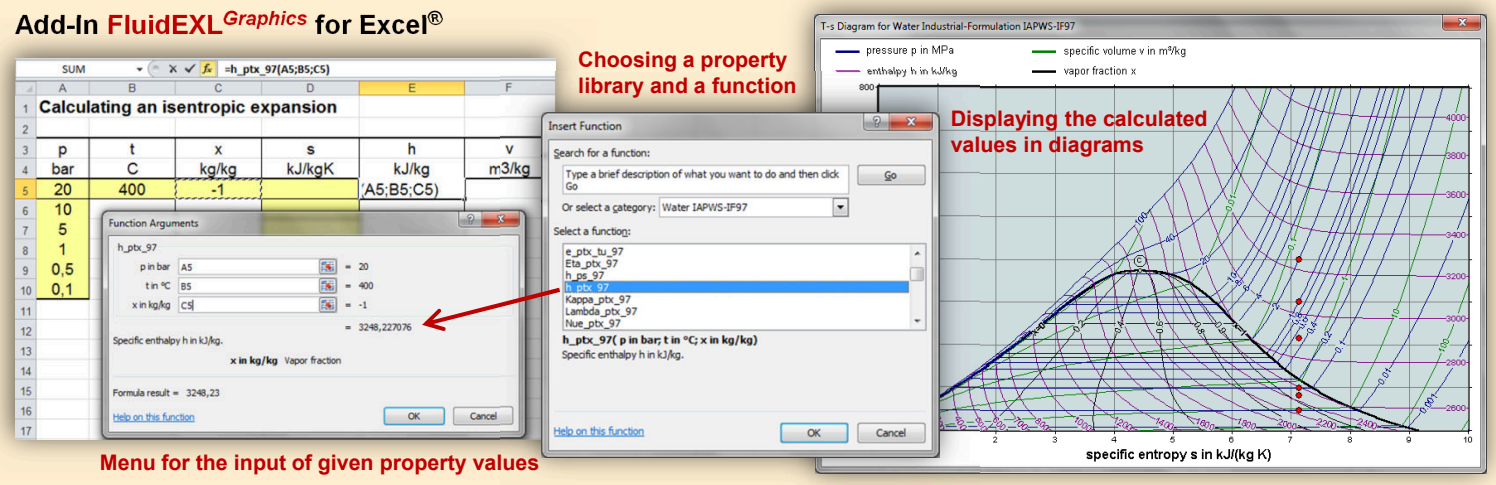
[a] Not all of these property functions are available in all property libraries.

KCE

KCE-ThermoFluidProperties
www.thermofluidprop.com

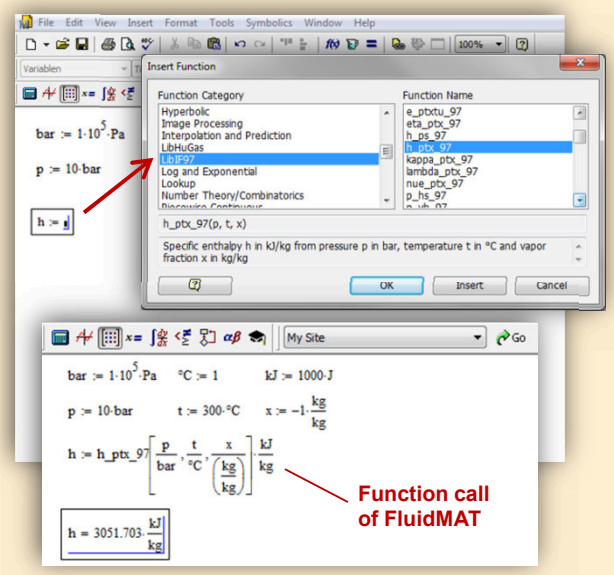
Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Add-In FluidEXL*Graphics* for Excel®



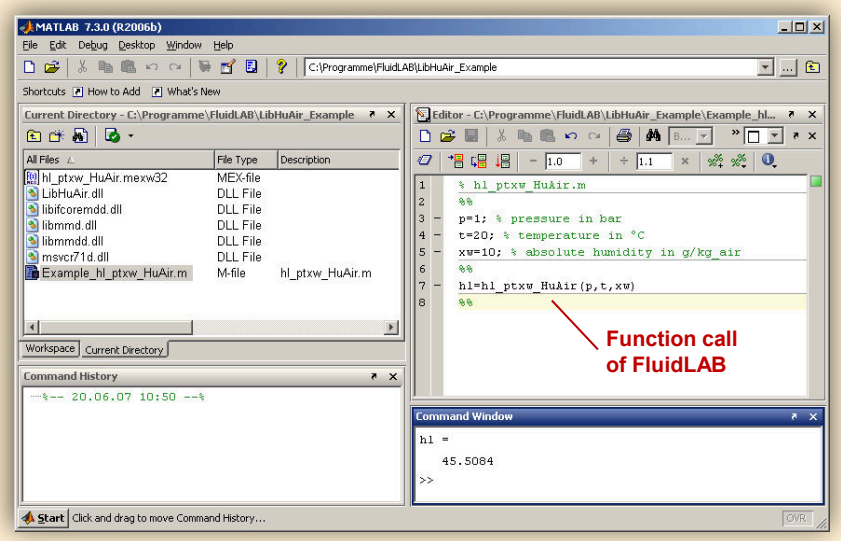
Add-In FluidMAT for Mathcad®

The property libraries can be used in Mathcad®.



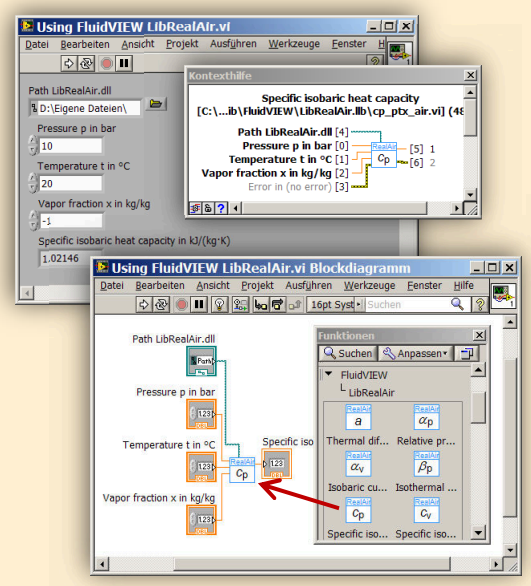
Add-In FluidLAB for MATLAB®

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



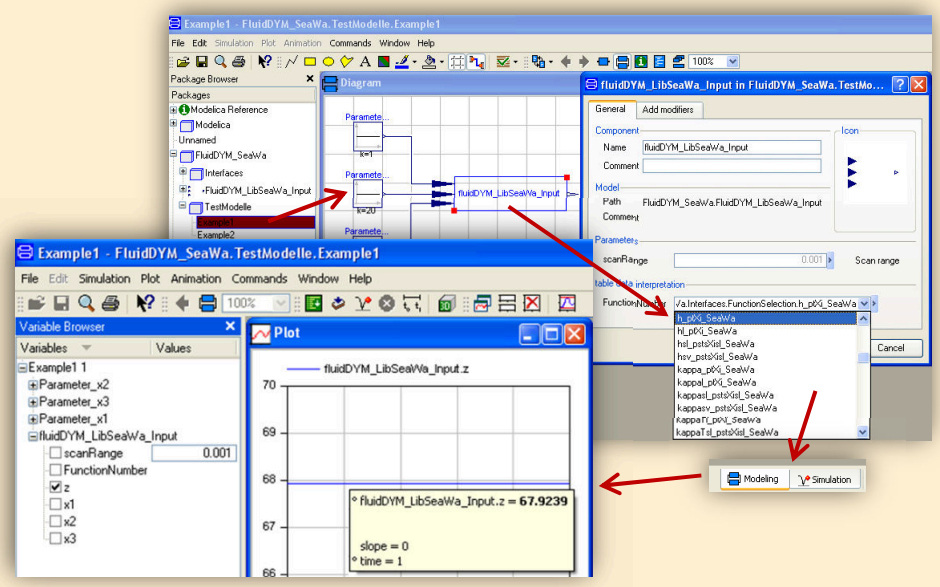
Add-On FluidVIEW for LabVIEW™

The property functions can be calculated in LabVIEW™.

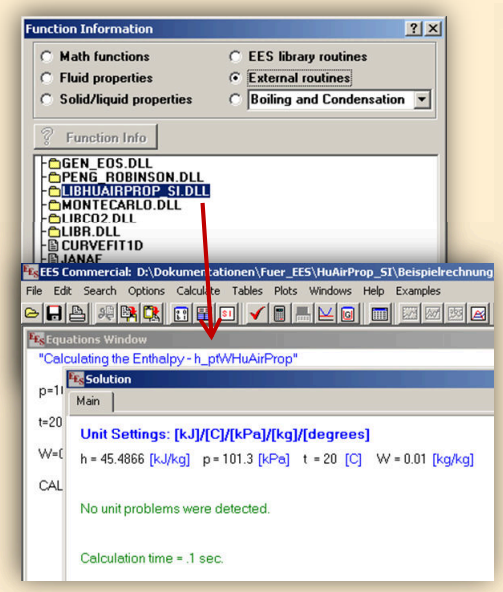


Add-In FluidDYM for DYMOLA® (Modelica) and SimulationX®

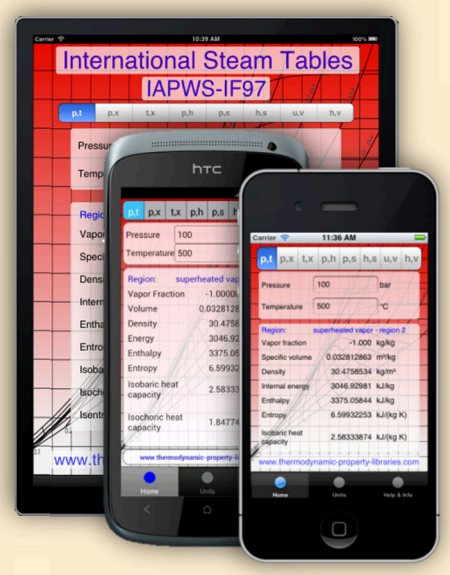
The property functions can be called in DYMOLA® and SimulationX®.



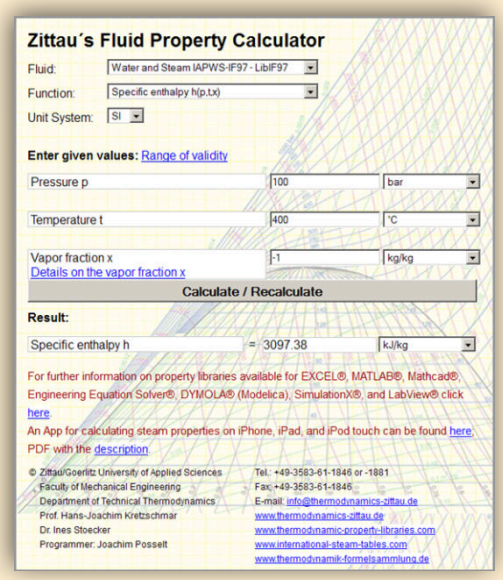
Add-In FluidEES for Engineering Equation Solver®



App International Steam Tables for iPhone, iPad, iPod touch, Android Smartphones and Tablets



Online Property Calculator at www.thermofluidprop.com

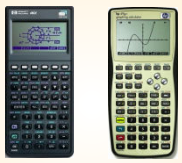


Property Software for Pocket Calculators

FluidCasio

fx 9750 G II | CFX 9850 fx-GG20 | CFX 9860 G Graph 85 | ALGEBRA FX 2.0

FluidHP



HP 48 | HP 49

FluidTI

TI Nspire CX CAS
TI Nspire CAS
TI 83
TI 84
TI 89
TI Voyage 200
TI 92

For more information please contact:

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Mobile: +49-172-7914607
Fax: +49-3222-4262250

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

www.thermofluidprop.com

5. References

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Available at the IAPWS website http://www.iapws.org

[9] Supplementary Release on Backward Equations for Specific Volume as a Function of Pressure and Temperature v(p,T) for Region 3 of the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam 2005. Available at the IAPWS website http://www.iapws.org

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6. Satisfied Customers

Date: 05/2018

The following companies and institutions use the property libraries

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

2018

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

2017

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

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

2016

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

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

2015

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

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

2014

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

2013

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

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

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

2012

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

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

2011

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

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

2010

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

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

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

2009

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

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

2008

Pink, Langenwang	01/2008
Fischer-Uhrig, Berlin	01/2008
University of Karlsruhe	01/2008
MAAG, Kuesnacht, Switzerland	02/2008
M&M Turbine Technology, Bielefeld	02/2008
Lentjes, Ratingen	03/2008
Siemens Power Generation, Goerlitz	04/2008
Evonik, Zwingenberg (general EBSILON program license)	04/2008
WEBASTO, Neubrandenburg	04/2008
CFC Solutions, Munich	04/2008
RWE IT, Essen	04/2008
Rerum Cognitio, Zwickau	04/2008, 05/2008
ARUP, Berlin	05/2008
Research Center, Karlsruhe	07/2008
AWECO, Neukirch	07/2008
Technical University of Dresden, Professorship of Building Services	07/2008
Technical University of Cottbus, Chair in Power Plant Engineering	07/2008, 10/2008
Ingersoll-Rand, Unicov, Czech Republic	08/2008

Technip Benelux BV, Zoetermeer, Netherlands	08/2008
Fennovoima Oy, Helsinki, Finland	08/2008
Fichtner Consulting & IT, Stuttgart	09/2008
PEU, Espenhain	09/2008
Poyry, Dresden	09/2008
WINGAS, Kassel	09/2008
TUEV Sued, Dresden	10/2008
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	10/2008, 11/2008
AWTEC, Zurich, Switzerland	11/2008
Siemens Power Generation, Erlangen	12/2008

2007

Audi, Ingolstadt	02/2007
ANO Abfallbehandlung Nord, Bremen	02/2007
TUEV NORD SysTec, Hamburg	02/2007
VER, Dresden	02/2007
Technical University of Dresden, Chair in Jet Propulsion Systems	02/2007
Redacom, Nidau, Switzerland	02/2007
Universität der Bundeswehr, Munich	02/2007
Maxxtec, Sinsheim	03/2007
University of Rostock, Chair in Technical Thermodynamics	03/2007
AGO, Kulmbach	03/2007
University of Stuttgart, Chair in Aviation Propulsions	03/2007
Siemens Power Generation, Duisburg	03/2007
ENTHAL Haustechnik, Rees	05/2007
AWECO, Neukirch	05/2007
ALSTOM, Rugby, Great Britain	06/2007
SAAS, Possendorf	06/2007
Grenzebach BSH, Bad Hersfeld	06/2007
Reichel Engineering, Haan	06/2007
Technical University of Cottbus, Chair in Power Plant Engineering	06/2007
Voith Paper Air Systems, Bayreuth	06/2007
Egger Holzwerkstoffe, Wismar	06/2007
Tissue Europe Technologie, Mannheim	06/2007
Dometic, Siegen	07/2007
RWTH Aachen University, Institute for Electrophysics	09/2007
National Energy Technology Laboratory, Pittsburg, USA	10/2007
Energieversorgung Halle	10/2007
AL-KO, Jettingen	10/2007
Grenzebach BSH, Bad Hersfeld	10/2007

Wiesbaden University of Applied Sciences, Department of Engineering Sciences	10/2007
Endress+Hauser Messtechnik, Hannover	11/2007
Munich University of Applied Sciences, Department of Mechanical Engineering	11/2007
Rerum Cognitio, Zwickau	12/2007
Siemens Power Generation, Erlangen	11/2007
University of Rostock, Chair in Technical Thermodynamics	11/2007, 12/2007

2006

STORA ENSO Sachsen, Eilenburg	01/2006
Technical University of Munich, Chair in Energy Systems	01/2006
NUTEC Engineering, Bisikon, Switzerland	01/2006, 04/2006
Conwel eco, Bochov, Czech Republic	01/2006
Offenburg University of Applied Sciences	01/2006
KOCH Transporttechnik, Wadgassen	01/2006
BEG Bremerhavener Entsorgungsgesellschaft	02/2006
Deggendorf University of Applied Sciences, Department of Mechanical Engineering and Mechatronics	02/2006
University of Stuttgart, Department of Thermal Fluid Flow Engines	02/2006
Technical University of Munich, Chair in Apparatus and Plant Engineering	02/2006
Energietechnik Leipzig (company license),	02/2006
Siemens Power Generation, Erlangen	02/2006, 03/2006
RWE Power, Essen	03/2006
WAETAS, Pobershau	04/2006
Siemens Power Generation, Goerlitz	04/2006
Technical University of Braunschweig, Department of Thermodynamics	04/2006
EnviCon & Plant Engineering, Nuremberg	04/2006
Brassel Engineering, Dresden	05/2006
University of Halle-Merseburg, Department of USET Merseburg incorporated society	05/2006
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	05/2006
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	05/2006
Suedzucker, Ochsenfurt	06/2006
M&M Turbine Technology, Bielefeld	06/2006
Feistel Engineering, Volkach	07/2006
ThyssenKrupp Marine Systems, Kiel	07/2006

Caliqua, Basel, Switzerland (company license)	09/2006
Atlas-Stord, Rodovre, Denmark	09/2006
Konstanz University of Applied Sciences, Course of Studies Construction and Development	10/2006
Siemens Power Generation, Duisburg	10/2006
Hannover University of Applied Sciences, Department of Mechanical Engineering	10/2006
Siemens Power Generation, Berlin	11/2006
Zikesch Armaturentechnik, Essen	11/2006
Wismar University of Applied Sciences, Seafaring Department	11/2006
BASF, Schwarzheide	12/2006
Enertech Energie und Technik, Radebeul	12/2006

2005

TUEV Nord, Hannover	01/2005
J.H.K Plant Engineering and Service, Bremerhaven	01/2005
Electrowatt-EKONO, Zurich, Switzerland	01/2005
FCIT, Stuttgart	01/2005
Energietechnik Leipzig (company license)	02/2005, 04/2005 07/2005
eta Energieberatung, Pfaffenhofen	02/2005
FZR Forschungszentrum, Rossendorf/Dresden	04/2005
University of Saarbruecken	04/2005
Technical University of Dresden Professorship of Thermic Energy Machines and Plants	04/2005
Grenzebach BSH, Bad Hersfeld	04/2005
TUEV Nord, Hamburg	04/2005
Technical University of Dresden, Waste Management	05/2005
Siemens Power Generation, Goerlitz	05/2005
Duesseldorf University of Applied Sciences, Department of Mechanical Engineering and Process Engineering	05/2005
Redacom, Nidau, Switzerland	06/2005
Dumas Verfahrenstechnik, Hofheim	06/2005
Alensys Engineering, Erkner	07/2005
Stadtwerke Leipzig	07/2005
SaarEnergie, Saarbruecken	07/2005
ALSTOM ITC, Rugby, Great Britain	08/2005
Technical University of Cottbus, Chair in Power Plant Engineering	08/2005
Vattenfall Europe, Berlin (group license)	08/2005
Technical University of Berlin	10/2005
Basel University of Applied Sciences, Department of Mechanical Engineering, Switzerland	10/2005

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

2004

Vattenfall Europe (group license)	01/2004
TUEV Nord, Hamburg	01/2004
University of Stuttgart, Institute of Thermodynamics and Heat Engineering	02/2004
MAN B&W Diesel A/S, Copenhagen, Denmark	02/2004
Siemens AG Power Generation, Erlangen	02/2004
Ulm University of Applied Sciences	03/2004
Visteon, Kerpen	03/2004, 10/2004
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	04/2004
Rerum Cognitio, Zwickau	04/2004
University of Saarbruecken	04/2004
Grenzebach BSH, Bad Hersfeld	04/2004
SOFBID Zwingenberg (general EBSILON program license)	04/2004
EnBW Energy Solutions, Stuttgart	05/2004
HEW-Kraftwerk, Tiefstack	06/2004
h s energieanlagen, Freising	07/2004
FCIT, Stuttgart	08/2004
Physikalisch Technische Bundesanstalt (PTB), Braunschweig	08/2004
Mainova Frankfurt	08/2004
Rietschle Energieplaner, Winterthur, Switzerland	08/2004
MAN Turbo Machines, Oberhausen	09/2004
TUEV Sued, Dresden	10/2004
STEAG Kraftwerk, Herne	10/2004, 12/2004
University of Weimar	10/2004
energeticals (e-concept), Munich	11/2004
SorTech, Halle	11/2004
Enertech EUT, Radebeul (company license)	11/2004
Munich University of Applied Sciences	12/2004
STORA ENSO Sachsen, Eilenburg	12/2004
Technical University of Cottbus, Chair in Power Plant Engineering	12/2004
Freudenberg Service, Weinheim	12/2004

2003

Paper Factory, Utzenstorf, Switzerland	01/2003
MAB Plant Engineering, Vienna, Austria	01/2003

Wulff Energy Systems, Husum	01/2003
Technip Benelux BV, Zoetermeer, Netherlands	01/2003
ALSTOM Power, Baden, Switzerland	01/2003, 07/2003
VER, Dresden	02/2003
Rietschle Energieplaner, Winterthur, Switzerland	02/2003
DLR, Leupholdhausen	04/2003
Emden University of Applied Sciences, Department of Technology	05/2003
Petterssson+Ahrends, Ober-Moerlen	05/2003
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