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

FluidMAT
with **LibIDGAS**
for Mathcad®

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Property Calculation for Combustion Gas Mixtures

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LibIDGAS FluidMAT for Mathcad®

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0 Package Contents

0.1 Zip file for 32-bit Mathcad®

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

"CD_FluidMAT_LibIDGAS.zip"

Combustion Gas Mixtures calculated from VDI-Guideline 4670

Including the following files:

FluidMAT_LibIDGAS_Setup.exe	- Self-extracting and self-installing program for FluidMAT
LibIDGAS.dll	- Dynamic Link Library for ideal gases and mixtures for use in Mathcad®
FluidMAT_LibIDGAS_Docu_Eng.pdf	- User's Guide

0.2 Zip file for 64-bit Mathcad®

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

"CD_FluidMAT_LibIDGAS_x64.zip"

Combustion Gas Mixtures calculated from VDI-Guideline 4670

Including the following files:

Files:

Setup.exe	- Self-extracting and self-installing program for FluidMAT
FluidMAT_LibIDGAS_64.msi	- Installation program for the FluidMAT Add-On for use in Mathcad®
LibIDGAS.dll	- Dynamic Link Library for ideal gases and mixtures for use in Mathcad®
FluidMAT_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 ₂ O
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
$a = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	a_pt_id	a_pt_id(p,t,type,zu(1:10))	Thermal diffusivity	m^2/s	[15], [18]	3/1
$c_p = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	cp_pt_id	cp_pt_id(p,t,type,zu(1:10))	Specific isobaric heat capacity	$\text{kJ}/(\text{kg} \cdot \text{K})$	[18]	3/2
$c_v = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	cv_pt_id	cv_pt_id(p,t,type,zu(1:10))	Specific isochoric heat capacity	$\text{kJ}/(\text{kg} \cdot \text{K})$	[18]	3/3
$\eta = f(t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	Eta_t_id	Eta_t_id(t,type,zu(1:10))	Dynamic viscosity	$\text{Pa} \cdot \text{s} = \text{kg}/(\text{m} \cdot \text{s})$	[15], [18]	3/4
$h = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	h_pt_id	h_pt_id(p,t,type,zu(1:10))	Specific enthalpy	kJ/kg	[18]	3/5
$\kappa = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	Kappa_pt_id	Kappa_pt_id(p,t,type,zu(1:10))	Isentropic exponent		[18]	3/6
$\lambda = f(t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	Lambda_t_id	Lambda_t_id(t,type,zu(1:10))	Thermal conductivity	$\text{W}/(\text{m} \cdot \text{K})$	[15]	3/7
$M = f(\xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	M_id	M_id(type,zu(1:10))	Molar mass of the mixture	kg/kmol	[17]	3/8
$\nu = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	Ny_pt_id	Ny_pt_id(p,t,type,zu(1:10))	Kinematic Viscosity	m^2/s	[15], [16]	3/9
$p = f(t, s, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	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
$p = f(t, v, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	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
$Pr = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	Pr_pt_id	Pr_pt_id(p,t,type,zu(1:10))	Prandtl-number		[15], [16]	3/12
$\psi_i = f(i, \xi_1 \dots \xi_{10})$	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
$R = f(\xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	R_id	R_id(type,zu(1:10))	Specific gas constant	$\text{kJ}/(\text{kg} \cdot \text{K})$	[17]	3/14
$\rho = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	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
$s = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	s_pt_id	s_pt_id(p,t,type,zu(1:10))	Specific entropy of the mixture	kJ/(kg · K)	[18]	3/16
$T = f(p, h, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	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
$t = f(p, s, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	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
$t = f(p, v, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	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
$u = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	u_pt_id	u_pt_id(p,t,type,zu(1:10))	Specific internal energy	kJ/kg		3/20
$v = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	v_pt_id	v_pt_id(p,t,type,zu(1:10))	Specific volume	m ³ /kg	Ideal gas equation	3/21
$w = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$	w_pt_id	w_pt_id(p,t,type,zu(1:10))	Isentropic speed of sound of the mixture	m/s	[18]	3/22
$\xi_i = f(i, \psi_1 \dots \psi_{10})$	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
$\xi_1 \dots \xi_{10}$	Mass fractions of the components	kg/kg
$\psi_1 \dots \psi_{10}$	Mole fractions, volume fractions of the components	kmol/kmol
type	Input: type = 1 for mass fractions $\xi_1, \dots, \xi_{10}$ type = 0 for mole fractions $\psi_1, \dots, \psi_{10}$	
comp(1:10) for type =1	Mass fractions $\xi_1, \dots, \xi_{10}$	kg/kg
comp(1:10) for type =0	Mole fractions $\psi_1, \dots, \psi_{10}$	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 ₂ O
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 <i>Brandt</i> [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 FluidMAT in Mathcad®

FluidMAT has been developed to calculate thermodynamic properties in Mathcad more conveniently. Within Mathcad it enables the direct call of functions relating to ideal mixtures of gases from the LibIDGAS property library.

2.1 Installing FluidMAT

This section describes the installation of FluidMAT LibIDGAS in Mathcad®.

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_FluidMAT_LibIDGAS.zip", you will see the folder

CD_FluidMAT_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:

FluidMAT_LibIDGAS_Docu_Eng.pdf

FluidMAT_LibIDGAS_Setup.exe

LibIDGAS.dll.

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

FluidMAT_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.

Now, you will be informed on the FluidMAT product in the "ReadMe-File" window (see Figure 2.1). Click "Next >" to leave this window.

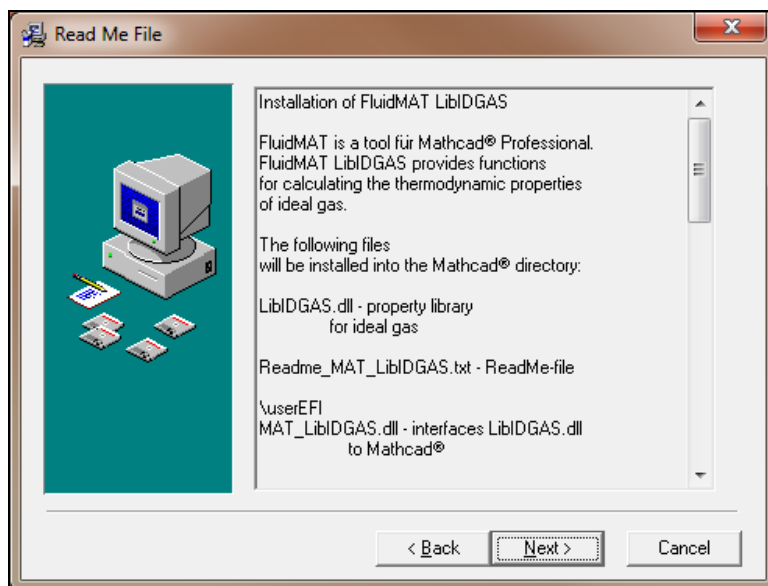


Figure 2.1: "Read Me File" dialog window

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

C:\Program Files\Mathcad\Mathcad 14 (for English version of Windows)
 C:\Programme\Mathcad\Mathcad 14 (for German version of Windows)

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

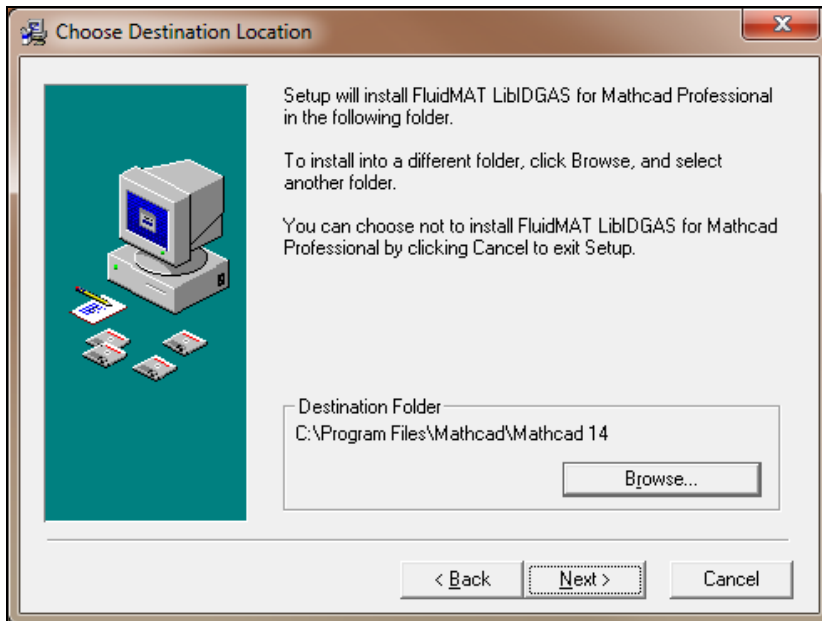


Figure 2.2: "Choose Destination Location" dialog window

The installation program has already detected and entered the correct Mathcad directory automatically. If this is not the case, e. g. if you there are two Mathcad versions installed on your system, please proceed as follows. By clicking the "Browse..." button, you can choose the directory in which the correct Mathcad version is installed.

The exact setting of the Mathcad directory is of vital importance for the correct installation of FluidMAT.

After you have entered the exact path of the Mathcad directory you can leave this window. Click on "Next >" to continue installation.

Now, click "Next >" again in the "Start Installation" window which follows in order to start the installation of FluidMAT with the LibIDGAS library.

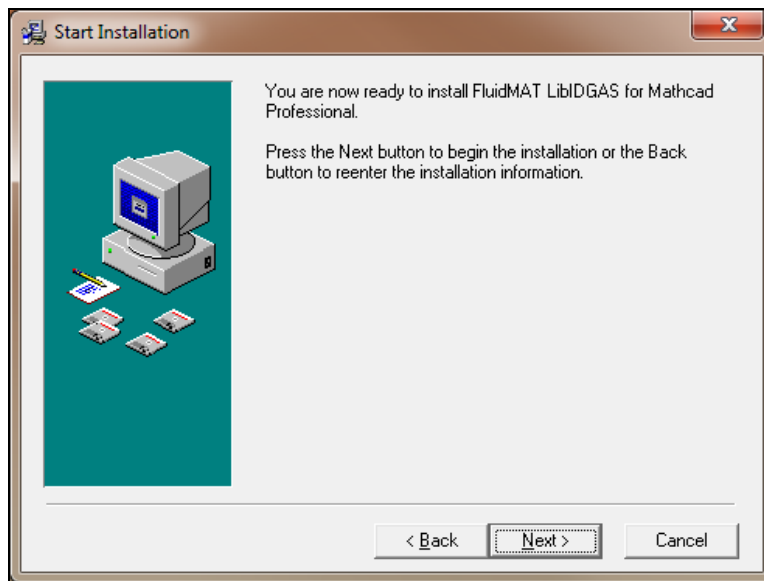


Figure 2.3: "Start Installation" dialog window

Now, the FluidMAT files are installed on your hard drive. You can watch the installation process in the dialog box "File is being installed". You will see the "Installation Complete" window after the process has finished (see Figure 2.4).

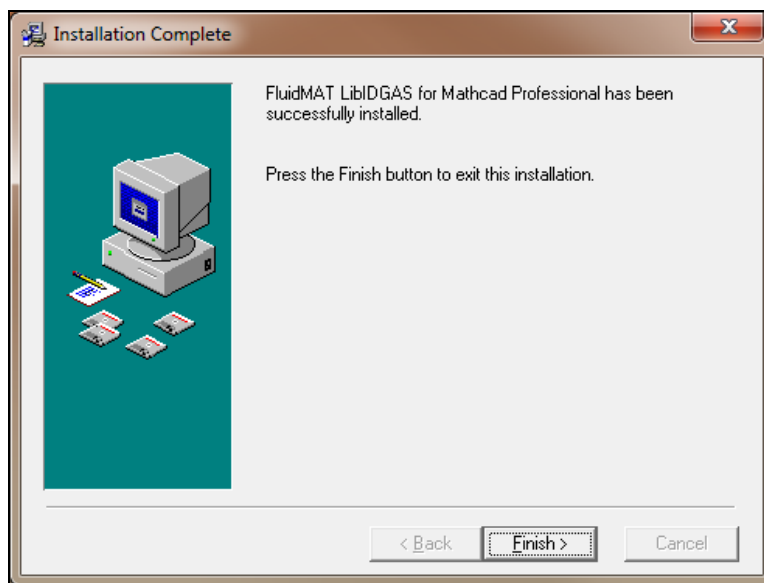


Figure 2.4: "Installation Complete" dialog window

Confirm this by clicking the "Finish>" button

Now, you have to overwrite the file

"LibIDGAS.dll"

in your Mathcad directory with the file of the same name provided in your CD folder with FluidMAT 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 Mathcad directory (the standard being

C:\Programme\Mathcad\Mathcad 14\ (for German version of Windows®)

C:\Program Files\Mathcad\Mathcad 14\ (for English 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.

Now, you have to overwrite the file

"MAT_LibIDGAS_EN.xml"

in your Mathcad directory with the file of the same name provided in your CD folder with FluidMAT LibIDGAS.

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

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

Now, open your Mathcad directory (the standard being

C:\Programme\Mathcad\Mathcad 14\doc\funcdoc (for German version of Windows®)

C:\Program Files\Mathcad\Mathcad 14\doc\funcdoc (for English version of Windows))

and insert the file "MAT_LibIDGAS_EN.xml" 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 "MAT_LibIDGAS_EN.xml" successfully.

From within Mathcad you can now select the property functions.

The installation program has made the following changes to your system:

The following files were installed into your Mathcad directory:

LibIDGAS.dll	Property library of IDGAS
Readme_MAT_LibIDGAS_.txt	ReadMe file
DFORRT.DLL	Dynamic link library for use in Windows® programs
MSVCRT.DLL	Dynamic link library for use in Windows® programs

The following file was installed into your Mathcad subdirectory \userEFI:

MAT_LibIDGAS.dll	Function definition of IDGAS in Mathcad
------------------	---

The following file was installed into your Mathcad subdirectory \doc:

MAT_LibIDGAS.chm	Helpful information on FluidMAT with LibIDGAS
------------------	---

The following files were installed into your Mathcad subdirectory \doc\funcdoc:

MAT_LibIDGAS.xml	Function registration in the dialog window "Insert Function" for LibIDGAS (Mathcad® version 11 or lower)
MAT_LibIDGAS_DE.xml	Function registration in the dialog window "Insert Function" for LibIDGAS (German Mathcad® version 12 or higher)
MAT_LibIDGAS_EN.xml	Function registration in the dialog window "Insert Function" for LibIDGAS (English Mathcad® version 12 or higher)

2.2 Licensing the LibIDGAS Property Library

The licensing procedure has to be carried out when you are calculating a function with LibIDGAS in Mathcad® and a FluidMAT prompt message appears. In this case, you will see the "License Information" window for LibIDGAS (see figure below).

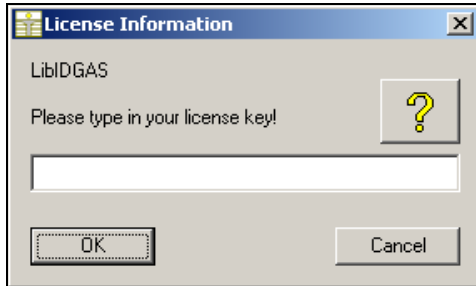


Figure 2.5: "License Information" window

Here you are asked to type in the license key which you have obtained from 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:

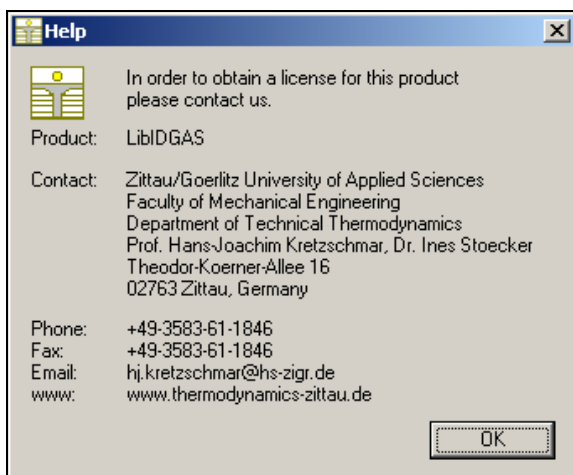


Figure 2.6: "Help" window

If you do not enter a valid license it is still possible to use Mathcad® by clicking "Cancel". In this case, the LibIDGAS property library will display the result "-1111111" for every calculation.

The "License Information" window will appear every time you use FluidMAT LibIDGAS until you enter a license code to complete registration.

If you decide not to use FluidMAT LibIDGAS, you can uninstall the program following the instructions given in section 2.4 of this User's Guide.

2.3 Example: Calculation of the Enthalpy $h = f(p, t, \xi_1 \dots \xi_{10})$ of the Gas Mixture

We will now calculate, step by step, the specific enthalpy h of a combustion gas as a function of pressure $p = 1$ bar, temperature $t = 100$ °C, and a mixture composed of the following mass fractions using FluidMAT:

13 % carbon dioxide, 11 % steam, and 76 % air nitrogen.

According to the "Mixture gases" table in Chapter 1.2, carbon dioxide represents in the LibIDGAS program library the gas no. 6, steam the gas no. 7 and air nitrogen the gas no. 10. Thus the mass fractions are

$$\xi_6 = 13\%, \quad \xi_7 = 11\%, \quad \xi_{10} = 76\%.$$

Please carry out the following steps:

- Start Mathcad.
- Type "h:" in the Mathcad window. Now, you will see $h := \blacksquare$.
- Click on "Insert" in the upper menu bar and then click "Function..."

The "Insert Function" window appears (see Figure 2.7)

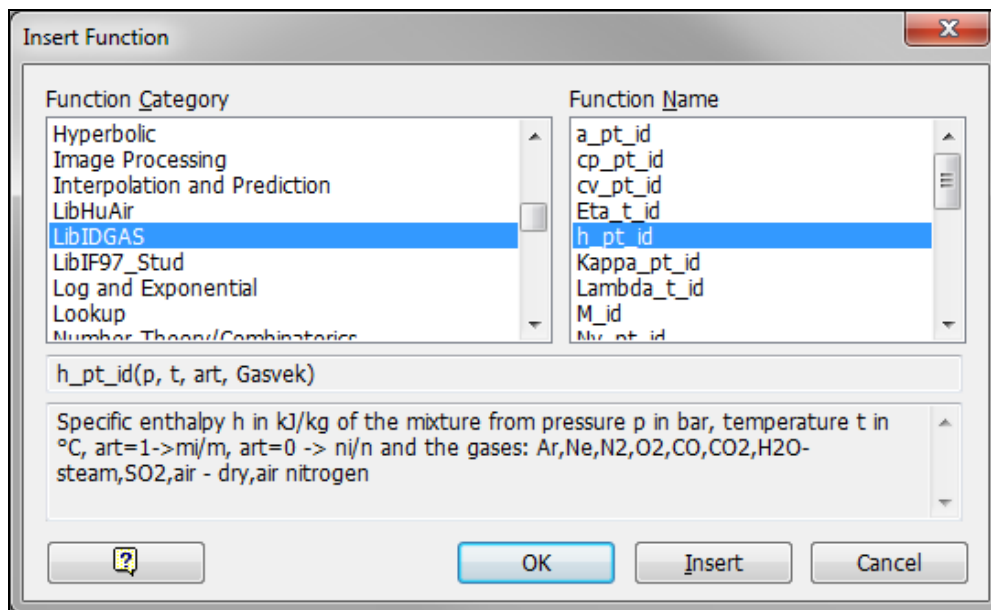


Figure 2.7: Choice of library and function name

- Click "LibIDGAS" under "Function Category" on the left hand side (see Figure 2.7)
- Choose "h_pt_id" under "Function Name" on the right hand side
- Now, click "OK" and you will see $h := h_{pt_id}(\blacksquare, \blacksquare, \blacksquare)$ in the Mathcad window (see next figure).

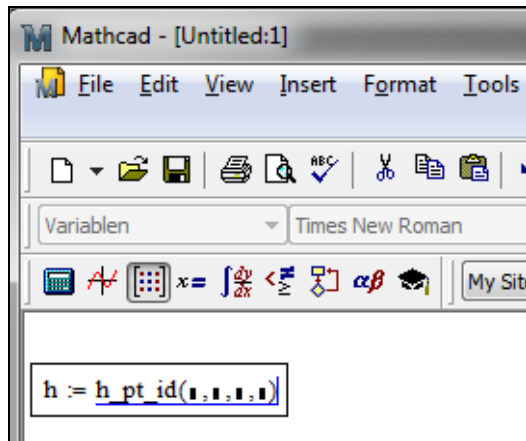


Figure 2.8: Example Mathcad® sheet with formula and placeholders

- The cursor is situated on the first operand.
- For the first operand: Enter the value for p in bar
(Range of validity: $p = 0.01 \text{ bar} \dots 50 \text{ bar}$)
e. g.: Enter the value 1 for the first operand
- Situate the cursor on the second operand.
- For the second operand: Enter the value for t in °C
(Range of validity: $t = -73.15 \text{ °C} \dots 3,026.85 \text{ °C}$)
e. g.: Enter the value 100 for the second operand
- Situate the cursor on the third operand.
- Enter the code "art" to identify if the composition of the mixture is entered in mass fractions or mole fractions, i. e. volume fractions
 - art = 1 for input of composition in mass fractions $\xi_1, \dots, \xi_{10}$
 - art = 0 for input of composition in mass fractions $\psi_1, \dots, \psi_{10}$
 e. g.: Enter the value 1 for the third operand
- Situate the cursor on the fourth operand.
Insert a matrix with ten rows and one column by clicking on the "Vector and Matrix Toolbar" button. Then click the "Matrix or Vector" button in the small window which appeared.
- Enter the values for the mass fractions $\xi_1 \dots \xi_{10}$ of the mixture gases into the vector

ξ_1 for argon	Ar	⇒ e. g.: Enter the value 0	into the 1 st row
ξ_2 for neon	Ne	⇒ e. g.: Enter the value 0	into the 2 nd row
ξ_3 for nitrogen	O ₂	⇒ e. g.: Enter the value 0	into the 3 rd row
ξ_4 for oxygen	N ₂	⇒ e. g.: Enter the value 0	into the 4 th row
ξ_5 for carbon monoxide	CO	⇒ e. g.: Enter the value 0	into the 5 th row
ξ_6 for carbon dioxide	CO ₂	⇒ e. g.: Enter the value 0.13	into the 6 th row
ξ_7 for steam	H ₂ O	⇒ e. g.: Enter the value 0.11	into the 7 th row
ξ_8 for sulfur dioxide	SO ₂	⇒ e. g.: Enter the value 0	into the 8 th row
ξ_9 for air - dry		⇒ e. g.: Enter the value 0	into the 9 th row
ξ_{10} for air nitrogen		⇒ e. g.: Enter the value 0.76	into the 10 th row

Confirm your entry by pressing the "ENTER" key.

Now, the Mathcad sheet should look like the next figure.

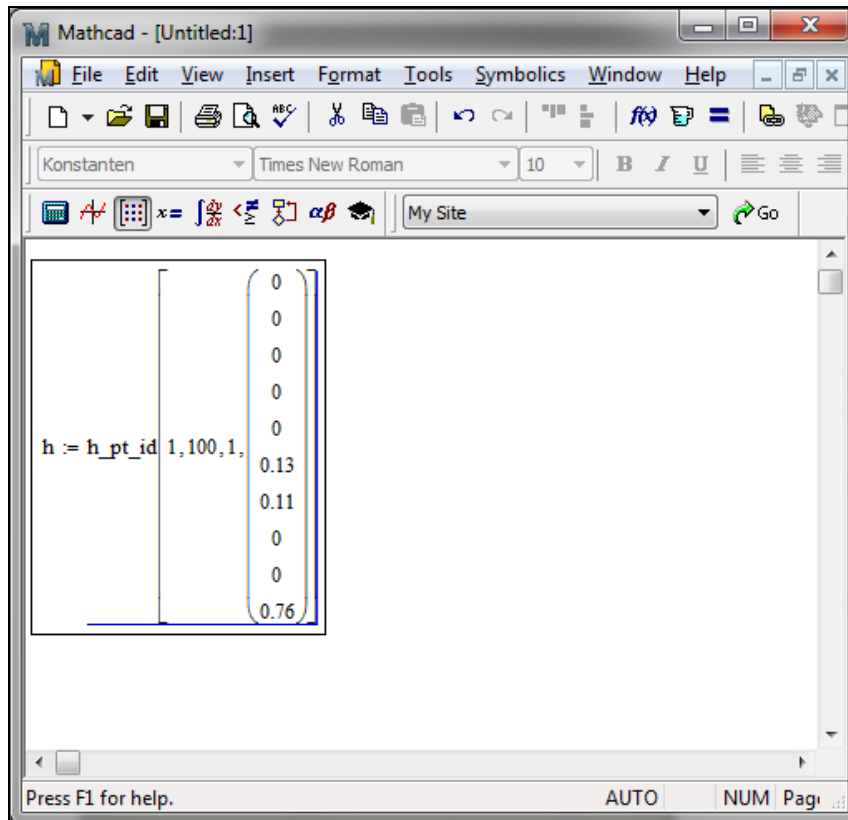


Figure 2.9: Example Mathcad® sheet with formula

- You can now go on working with the variable h which we have just calculated or you can have the result for this calculated. If you wish to see the result, type the command "**h =**" on the next line in the Mathcad window

You will now see the result $h = 385.398 \text{ kJ/kg}$ (see Figure 2.10).

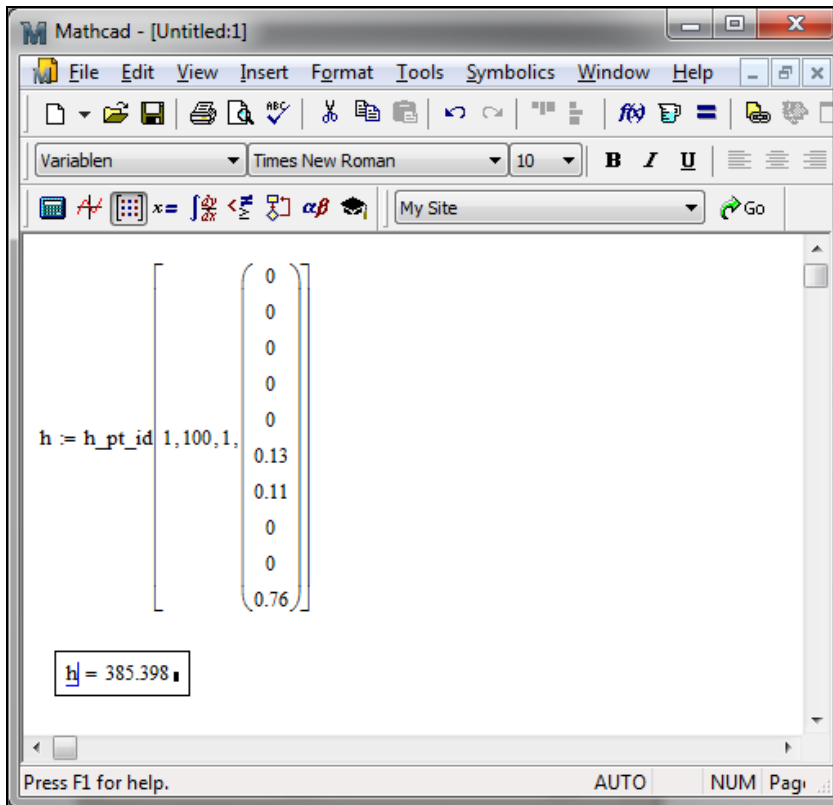


Figure 2.10: Example Mathcad® sheet with finished calculation

The representation of the result depends on the amount of places and decimal places which you have set before. You can also multiply the result of the functional equation by the measuring unit in order to see the result together with the measuring unit.

It is necessary to define this measuring unit before (in our example calculation it would be kJ/kg).

You can now arbitrarily change the values for p , t or ξ . The enthalpy is recalculated and updated every time you change the data. This shows that the Mathcad data flow and the DLL calculations are working together successfully.

2.4 Removing FluidMAT

To remove FluidMAT LibIDGAS from Mathcad® and your hard drive, carry out the following steps:

- Click the "Start" button in the Windows® task bar
- Click "Settings"
- Click "Control Panel"
- Double click "Add or Remove Programs"
- Click on "FluidMAT LibIDGAS" in the list box
- Click the "Add or Remove" button
- Mark "Automatic" and click the "Next >" button
- Click "Finish" in the "Perform Uninstall" window

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

Now FluidMAT LibIDGAS has been removed.

3. Program Documentation

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

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

Subprogram with parameter: **INTEGER*4 FUNCTION C_A_PT_ID(A,P,T,ART, ZU)**
 for the call out of the DLL **REAL*8 A, P, T, ZU(0:10)**
INTEGER*4 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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:

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

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 [18]
 ρ for ideal gas mixture

Specific Isobaric Heat Capacity $c_p = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$

Function Name: **cp_pt_id**

Subprogram with value of the function: **REAL*8 FUNCTION CP_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_CP_PT_ID(CP,P,T,ART, COMP)**
 for the call out of the DLL **REAL*8 CP, P, T, COMP(0:10)**
INTEGER*4 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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 $\psi_{\text{H}_2\text{O}} \geq 0.1$

Results for wrong input values:

cp_pt_id, cp = -1

References:

c_p corresponding to VDI 4670 [18]

Specific Isochoric Heat Capacity $c_v = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$

Function Name: **cv_pt_id**

Subprogram with value of the function: **REAL*8 FUNCTION CV_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_CV_PT_ID(CV,P,T,ART, COMP)**
 for the call out of the DLL **REAL*8 CV, P, T, COMP(0:10)**
INTEGER*4 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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 [18]

Dynamic Viscosity $\eta = f(t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$

Function Name: **Eta_t_id**

Subprogram with value of the function: **REAL*8 FUNCTION ETA_T_ID(P,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_ETA_T_ID(ETA,T,ART, COMP)**
 for the call out of the DLL REAL*8 ETA, T, COMP(0:10)
 INTEGER*4 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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 according to *Brandt*

Results for wrong input values:

Eta_t_id, Eta = -1

References:

Unsaturated and saturated humid air:
 η corresponding to *Brandt* [15]

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

Function Name: **h_pt_id**

Subprogram with value of the function: **REAL*8 FUNCTION H_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_H_PT_ID(H,P,T,ART, COMP)**
 for the call out of the DLL **REAL*8 H, P, T, COMP(0:10)**
INTEGER*4 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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 $\psi_{\text{H}_2\text{O}} \geq 0.1$

Results for wrong input values:

h_pt_id, h = -1

References:

h corresponding to VDI 4670 [18]

Isentropic Exponent $\kappa = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$

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 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
- Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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:

$$\text{Kappa } \kappa = \frac{c_p}{c_p - R}$$

Results for wrong input values:

Kappa_pt_id, Kappa = -1

References:

Unsaturated and saturated humid air:

c_p corresponding to VDI 4670 [18]

Thermal Conductivity $\lambda = f(t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$

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 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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 according *Brandt*

Results for wrong input values:

Lambda_t_id, Lambda = -1

References:

Unsaturated and saturated humid air:

λ corresponding to *Brandt* [15]

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

Function Name: **M_id**

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

Subprogram with parameter: **INTEGER*4 FUNCTION C_M_ID(M, ART, COMP)**
 for the call out of the DLL REAL*8 M, COMP(0:10)
 INTEGER*4 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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* [17]

Kinematic Viscosity $\nu = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$

Function Name: **Ny_pt_id**

Subprogram with value of the function: **REAL*8 FUNCTION NY_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_NY_PT_ID(CV,P,T,ART, COMP)**
 for the call out of the DLL **REAL*8 NY, P, T, COMP(0:10)**
INTEGER*4 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ in kmol/kmol for type = 0

Result:

Ny_pt_id, Nue - Kinematic viscosity in m²/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 $p = f(t, s, \xi_1 \dots \xi_{10}$ or $\psi_1 \dots \psi_{10}$)

Function Name: **p_ts_id**

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

Subprogram with parameter: **INTEGER*4 FUNCTION C_P_TS_ID(P,T,S,ART, COMP)**
 for the call out of the DLL **REAL*8 P, T, S, COMP(0:10)**
INTEGER*4 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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:

- Calculation according to *Brandt* considering 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 [18]

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

Function Name: **p_tv_id**

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

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

Input Values:

- v - Specific volume v in m^3/kg
- t - Temperature t in $^{\circ}\text{C}$
- type =1 for composition in mass fractions ξ
 =0 for composition in mole fractions ψ
- comp(1:10) - Composition in mass fractions $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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 $5.1 \text{ m}^3/\text{kg}$ to $2.9 \cdot 10^9 \text{ m}^3/\text{kg}$

Comments:

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

Results for wrong input values:

p_tv_id, p = -1

PRANDTL-Number $Pr = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$

Function Name: **Pr_pt_id**

Subprogram with value of the function: **REAL*8 FUNCTION PR_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_PR_PT_ID(PR,P,T,ART, COMP)**
 for the call out of the DLL **REAL*8 PR, P, T, COMP(0:10)**
INTEGER*4 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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 [18]

Mole Fraction $\psi_i = f(i, \xi_1 \dots \xi_{10})$

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 ART

Input Values:

i - Gas number
comp(1:10) - Composition in mass fractions $\xi_1 \dots \xi_{10}$ 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 $R = f(\xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$

Function Name: **R_id**

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

Subprogram with parameter: **INTEGER*4 FUNCTION C_R_ID(R, ART, COMP)**
 for the call out of the DLL **REAL*8 R, COMP(0:10)**
INTEGER*4 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ in kmol/kmol for type = 0

Result:

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

Comments:

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

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

Results for wrong input values:

R_id, R = -1

Density $\rho = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$

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 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
- Composition in mole fractions $\psi_1 \dots \psi_{10}$ in kmol/kmol for type = 0 |

Result:

Rho_pt_id, Rho - Density in kg/m³

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: $\rho = \frac{p}{R \cdot T}$

Results for wrong input values:

Rho_pt_id, Rho = -1

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

Function Name: **s_pt_id**

Subprogram with value of the function: **REAL*8 FUNCTION S_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_S_PT_ID(S,P,T,ART, COMP)**
 for the call out of the DLL REAL*8 S, P, T, COMP(0:10)
 INTEGER*4 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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 $\psi_{\text{H}_2\text{O}} \geq 0.1$

Results for wrong input values:

s_pt_id, s = -1

References:

s corresponding to VDI 4670 [18]

Backward Function: Temperature $t = f(p, h, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$

Function Name: **t_ph_id**

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

Subprogram with parameter: **INTEGER*4 FUNCTION C_T_PH_ID(T,P,H,ART, COMP)**
 for the call out of the DLL **REAL*8 T, P, H, COMP(0:10)**
INTEGER*4 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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 = -1

References:

h corresponding to VDI 4670 [18]

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

Function Name: **t_ps_id**

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

Subprogram with parameter: **INTEGER*4 FUNCTION C_T_PS_ID(T,P,S,ART, COMP)**
 for the call out of the DLL **REAL*8 T, P, S, COMP(0:10)**
INTEGER*4 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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 = -1

References:

s corresponding to VDI 4670 [18]

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

Function Name: **t_pv_id**

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

Subprogram with parameter: **INTEGER*4 FUNCTION C_T_PV_ID(T,P,V,ART, COMP)**
 for the call out of the DLL **REAL*8 T, P, V, COMP(0:10)**
INTEGER*4 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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 $5.1 \text{ m}^3/\text{kg}$ to $2.9 \cdot 10^9 \text{ m}^3/\text{kg}$

Comments:

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

Results for wrong input values:

t_pv_id, t = -1

Specific Internal Energy $u = f(p, t, \xi_1 \dots \xi_{10}$ or $\psi_1 \dots \psi_{10}$)

Function Name: **u_pt_id**

Subprogram with value of the function: **REAL*8 FUNCTION U_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_U_PT_ID(U,P,T,ART, COMP)**
 for the call out of the DLL **REAL*8 U, P, T, COMP(0:10)**
INTEGER*4 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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: $u = h(p, t, (1:10)) - R \cdot T$

Results for wrong input values:

u_pt_id, u = -1

References:

h corresponding to VDI 4670 [18]

Specific Volume $v = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$

Function Name: **v_pt_id**

Subprogram with value of the function: **REAL*8 FUNCTION V_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_V_PT_ID(V,P,T,ART, COMP)**
 for the call out of the DLL **REAL*8 V, P, T, COMP(0:10)**
INTEGER*4 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ in kmol/kmol for type = 0

Result:

v_pt_id, v - Specific volume in m³/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 $w = f(p, t, \xi_1 \dots \xi_{10} \text{ or } \psi_1 \dots \psi_{10})$

Function Name: **w_pt_id**

Subprogram with value of the function: **REAL*8 FUNCTION W_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_W_PT_ID(W,P,T,ART, COMP)**
 for the call out of the DLL **REAL*8 W, P, T, COMP(0:10)**
INTEGER*4 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 $\xi_1 \dots \xi_{10}$ in kg/kg for type = 1
 - Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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:
$$w = \sqrt{\frac{R_m \cdot T \cdot c_p}{c_p - R_m}}$$

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

Results for wrong input values:

w_pt_id, w = -1

References:

c_p corresponding to VDI 4670 [18]

Mass Fraction $\xi_i = f(i, \psi_1 \dots \psi_{10})$

Function Name: **Xsi_igas_Psi_id**

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

Subprogram with parameter: **INTEGER*4 FUNCTION C_XSI_IGAS_ID(XSI, IGAS, COMP)**
 for the call out of the DLL REAL*8 XSI, IGAS, COMP(0:10)
 INTEGER*4 ART

Input Values:

i - Gas number
 comp(1:10) - Composition in mole fractions $\psi_1 \dots \psi_{10}$ 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



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

Water and Steam

Library LibIF97

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

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:
CO₂ - Span and Wagner O₂ - Schmidt and Wagner
H₂O - IAPWS-95 Ar - Tegeler et al.
N₂ - Span et al.
and of the ideal gases:
SO₂, CO, Ne (Scientific Formulation of Bückner et al.)
Consideration of:
Dissociation from VDI 4670 and Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:

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

Consideration of:

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

Carbon Dioxide including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1994)

Seawater

Library LibSeaWa

IAPWS 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 H₂O F₂ Propane
N₂ SO₂ NH₃ Iso-Butane
O₂ H₂ Methane n-Butane
CO H₂S Ethane Benzene
CO₂ OH Ethylene Methanol
Air

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Dry Air including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Nitrogen

Library LibN2

Formulation of Span et al. (2000)

Hydrogen

Library LibH2

Formulation of Leachman et al. (2007)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth (1995)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bückner et al. (2003)

n-Butane

Library LibButane_n

Formulation of Bückner et al. (2003)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

IAPWS Guideline 2001 of Tillner-Roth and Friend (1998)
Helmholtz energy equation for the mixing term (also useable for calculating Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)
Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with
C₂H₆O₂ Ethylene glycol
C₃H₈O₂ Propylene glycol
C₂H₅OH Ethyl alcohol
CH₃OH Methyl alcohol
C₃H₈O₃ Glycerol
K₂CO₃ Potassium carbonate
CaCl₂ Calcium chloride
MgCl₂ Magnesium chloride
NaCl Sodium chloride
C₂H₃KO₂ Potassium acetate
Formulation of the International Institute of Refrigeration (1997)

Siloxanes as ORC Working Fluids

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

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

Tetradecamethylhexasiloxane $C_{14}H_{42}O_6Si_6$ **Library LibMD4M**

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Propane

Library LibPropane

Formulation of Lemmon et al. (2007)

Methanol

Library LibCH3OH

Formulation of de Reuck and Craven (1993)

Ethanol

Library LibC2H5OH

Formulation of Schroeder et al. (2012)

Helium

Library LibHe

Formulation of Arp et al. (1998)

Hydrocarbons

Decane $C_{10}H_{22}$ **Library LibC10H22**

Isopentane C_5H_{12} **Library LibC5H12_ISO**

Neopentane C_5H_{12} **Library LibC5H12_NEO**

Isohexane C_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**

Dinitrogen monoxide 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:

Zittau/Goerlitz University of Applied Sciences
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Theodor-Koerner-Allee 16
02763 Zittau, Germany

Internet: www.thermodynamics-zittau.de

E-mail: hj.kretzschmar@hszg.de

Phone: +49-3583-61-1846

Fax.: +49-3583-61-1846

The following thermodynamic and transport properties can be calculated^a:

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

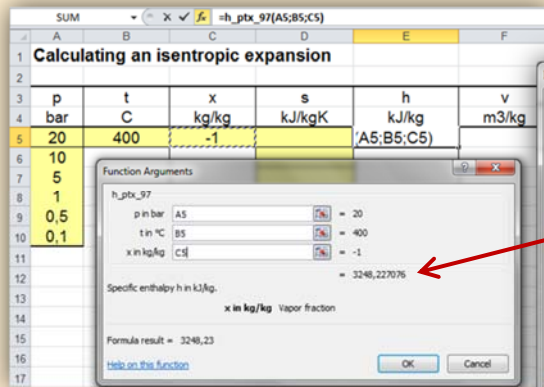
- Partial derivatives can be calculated.

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

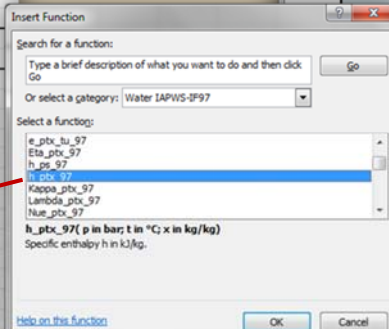


Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

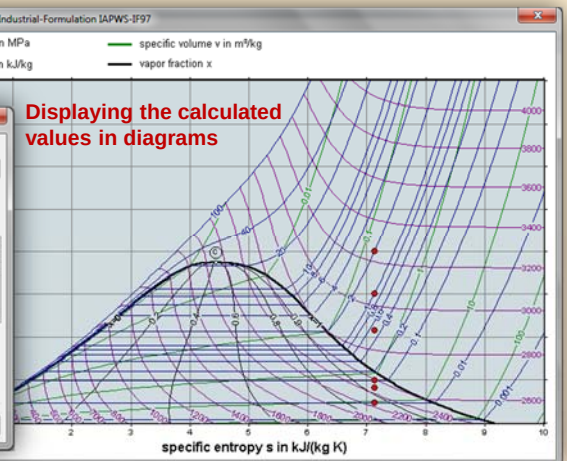
Add-In FluidEXL^{Graphics} for Excel[®]



Choosing a property library and a function



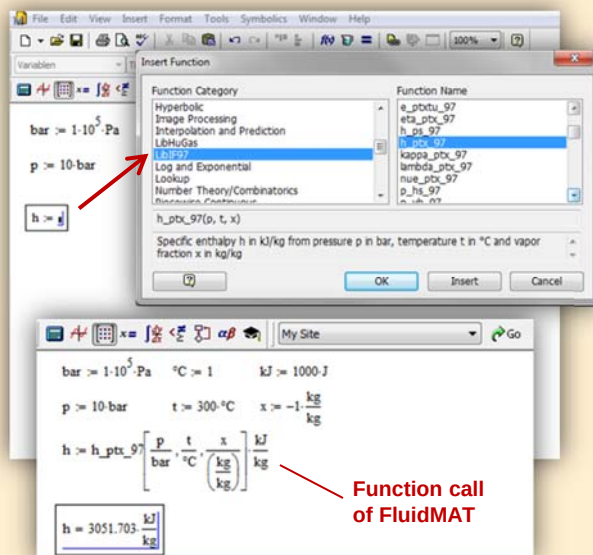
Displaying the calculated values in diagrams



Menu for the input of given property values

Add-In FluidMAT for Mathcad[®]

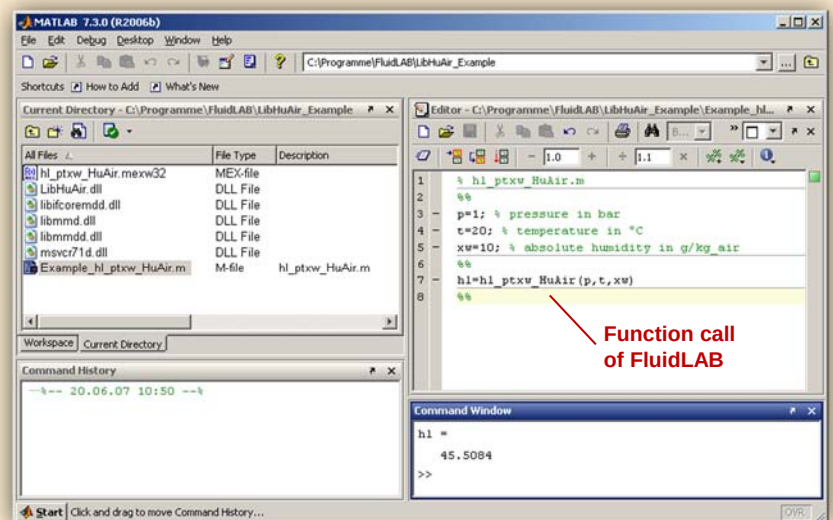
The property libraries can be used in Mathcad[®].



Function call of FluidMAT

Add-In FluidLAB for MATLAB[®]

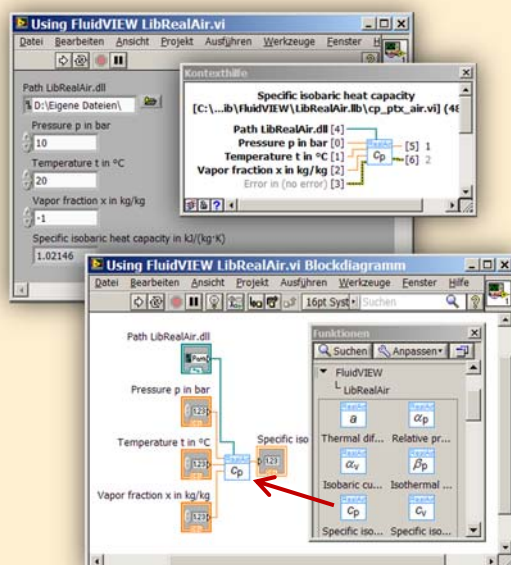
Using the Add-In FluidLAB the property functions can be called in MATLAB[®].



Function call of FluidLAB

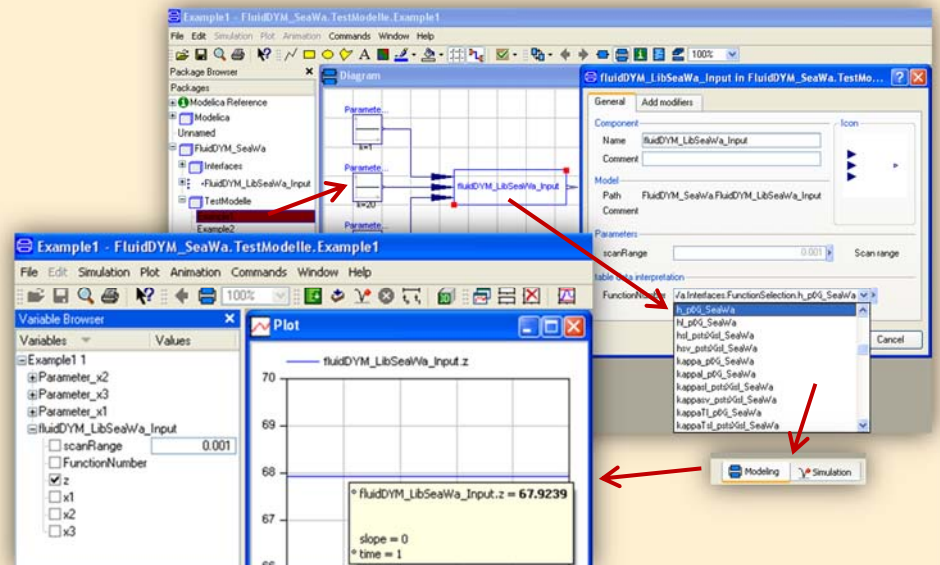
Add-On FluidVIEW for LabVIEW[®]

The property functions can be calculated in LabVIEW[®].

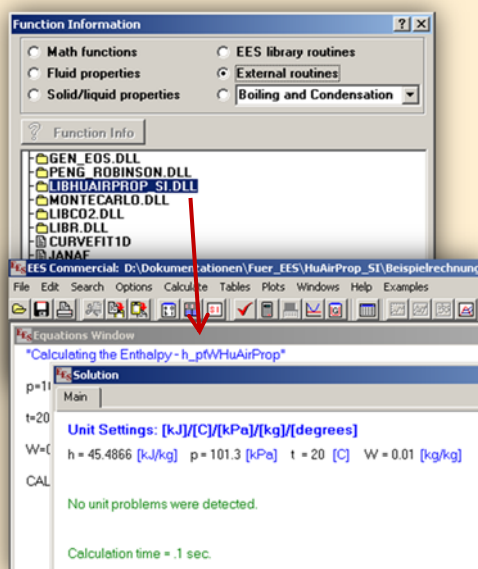


Add-In FluidDYM for DYMOLA[®] (Modelica) and SimulationX[®]

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



Add-In FluidEES for Engineering Equation Solver®



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



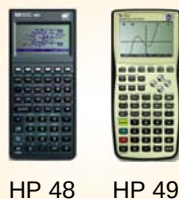
Online Property Calculator at www.thermodynamics-zittau.de

Property Software for Pocket Calculators

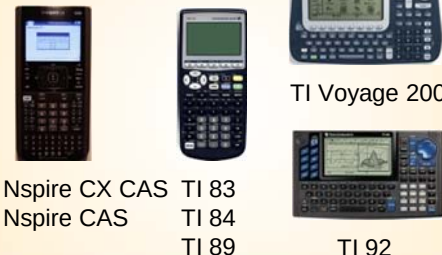
FluidCasio



FluidHP



FluidTI



For more information please contact:

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

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

5. References

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6. Satisfied Customers

Date: 04/2014

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[®]:

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 Nurnberg	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, Nürnberg	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 for RWE Essen	08/2013, 11/2013 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 Dresden + 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 Ingenieurbüro, 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
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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
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Concordia University, Montreal, Canada	09/2010
Compañía Eléctrica de Sochagota, Bogota, Colombia	08/2010
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TF Design, Matieland, South Africa	07/2010
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RWE IT, Essen	06/2010
Glen Dimplex, Kulmbach	05/2010, 07/2010 10/2010
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NIST Boulder CO, USA	03/2010
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ALSTOM Power, Baden, Switzerland	02/2010, 05/2010
MIT Massachusetts Institute of Technology Cambridge MA, USA	02/2010
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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
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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
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ENERKO, Aldenhoven	12/2009
2008	
Pink, Langenwang	01/2008
Fischer-Uhrig, Berlin	01/2008
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CFC Solutions, Munich	04/2008
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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
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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
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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, Bochoy, 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
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RWE Power, Essen	03/2006
WAETAS, Poberschau	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
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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	04/2005
Professorship of Thermic Energy Machines and Plants	
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
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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
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MAN B&W Diesel A/S, Copenhagen, Denmark	02/2004
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Ulm University of Applied Sciences	03/2004
Visteon, Kerpen	03/2004, 10/2004
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	04/2004
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University of Saarbruecken	04/2004
Grenzebach BSH, Bad Hersfeld	04/2004
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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
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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
Pettersson+Ahrends, Ober-Moerlen	05/2003
SOFBID ,Zwingenberg (general EBSILON program license)	05/2003
Ingenieurbuero Ostendorf, Gummersbach	05/2003
TUEV Nord, Hamburg	06/2003
Muenstermann GmbH, Telgte-Westbevern	06/2003
University of Cali, Colombia	07/2003
Atlas-Stord, Rodovre, Denmark	08/2003
ENERKO, Aldenhoven	08/2003
STEAG RKB, Leuna	08/2003
eta Energieberatung, Pfaffenhofen	08/2003
exergie, Dresden	09/2003
AWTEC, Zurich, Switzerland	09/2003
Energie, Timelkam, Austria	09/2003
Electrowatt-EKONO, Zurich, Switzerland	09/2003
LG, Annaberg-Buchholz	10/2003
FZR Forschungszentrum, Rossendorf/Dresden	10/2003
EnviCon & Plant Engineering, Nuremberg	11/2003
Visteon, Kerpen	11/2003
VEO Vulkan Energiewirtschaft Oderbruecke, Eisenhuettenstadt	11/2003
Stadtwerke Hannover	11/2003
SaarEnergie, Saarbruecken	11/2003
Fraunhofer-Gesellschaft, Munich	12/2003
Erfurt University of Applied Sciences, Department of Supply Engineering	12/2003
SorTech, Freiburg	12/2003
Mainova, Frankfurt	12/2003
Energieversorgung Halle	12/2003

2002

Hamilton Medical AG, Rhaezuens, Switzerland	01/2002
Bochum University of Applied Sciences, Department of Thermo- and Fluid Dynamics	01/2002
SAAS, Possendorf/Dresden	02/2002
Siemens, Karlsruhe (general license for the WinIS information system)	02/2002
FZR Forschungszentrum, Rossendorf/Dresden	03/2002

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Siemens Power Generation, Goerlitz	10/2002
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G.U.N.T. Geraetebau, Barsbuettel (general license and training test benches)	12/2002
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2001

ALSTOM Power, Baden, Switzerland	01/2001, 06/2001 12/2001
KW2 B. V., Amersfoot, Netherlands	01/2001, 11/2001
Eco Design, Saitamaken, Japan	01/2001
M&M Turbine Technology, Bielefeld	01/2001, 09/2001
MVV Energie, Mannheim	02/2001
Technical University of Dresden, Department of Power Machinery and Plants	02/2001
PREUSSAG NOELL, Wuerzburg	03/2001
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	04/2001
Muenstermann GmbH, Telgte-Westbevern	05/2001
SaarEnergie, Saarbruecken	05/2001

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Neusiedler AG, Ulmerfeld, Austria	09/2001
h s energieanlagen, Freising	09/2001
Electrowatt-EKONO, Zurich, Switzerland	09/2001
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VAUP Process Automation, Landau	08/2000
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Compania Electrica, Bogota, Colombia	10/2000
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Bayernwerk, Munich	01/1999
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Technical University of Graz, Department of Thermal Engineering, Austria	11/1999
Ostendorf Engineering, Gummersbach	12/1999

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Technical University of Cottbus, Chair in Power Plant Engineering	05/1998
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Gerb, Dresden	06/1997
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