Hochschule Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

Faculty of
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Department of
TECHNICAL THERMODYNAMICS

Property Library for Humid Gas Mixtures

FluidLAB
with LibHuGas
for MATLAB®

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Property Software for Humid Gas Mixtures Calculated as Ideal Mixture of Real Fluids

FluidLAB

for Matlab®

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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_LibHuGas.zip"

Including the following files:

FluidLAB_LibHuGas_Setup.exe	- Installation program for the FluidLAB Add-On for use in MATLAB®
LibHuGas.dll	- Dynamic Link Library for ideal mixtures of real fluids for use in MATLAB®
FluidLAB_LibHuGas_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_LibHuGas_x64.zip"

Including the following files and folders:

Files:

Setup.exe	- Self-extracting and self-installing program for FluidLAB
FluidLAB_LibHuGas_64.msi	- Installation program for the FluidLAB Add-On for use in MATLAB®
LibHuGas.dll	- Dynamic Link Library for ideal mixtures of real fluids for use in MATLAB®
FluidLAB_LibHuGas_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

Function	Function Name	Call of Fortran Program	Property or Function	Unit
$a = \mathrm{f}(p,t)$	a_ptcomp_HuGas	= a_pTcomp_HuGas(p,T,type,comp)	Thermal diffusivity	m^2/s
$c_p = \mathrm{f}(h,s)$	cp_hscomp_HuGas	= cp_hscomp_HuGas(h,s,type,comp)	Backward function: Specific isobaric heat capacity from enthalpy and entropy	$kJ/(kg \cdot K)$
$c_p = \mathrm{f}(p,h)$	cp_phcomp_HuGas	= cp_phcomp_HuGas(p,h,type,comp)	Backward function: Specific isobaric heat capacity from pressure and enthalpy	$kJ/(kg \cdot K)$
$c_p = \mathrm{f}(p,s)$	cp_pscomp_HuGas	= cp_pscomp_HuGas(p,s,type,comp)	Backward function: Specific isobaric heat capacity from pressure and entropy	$kJ/(kg \cdot K)$
$c_p = \mathrm{f}(p,t)$	cp_ptcomp_HuGas	= cp_pTcomp_HuGas(p,T,type,comp)	Specific isobaric heat capacity	$kJ/(kg \cdot K)$
$c_p = \mathrm{f}(t,s)$	cp_tscomp_HuGas	= cp_Tscomp_HuGas(T,s,type,comp)	Backward function: Specific isobaric heat capacity from temperature and entropy	$kJ/(kg \cdot K)$
$c_v = \mathrm{f}(p,t)$	cv_ptcomp_HuGas	= cv_pTcomp_HuGas(p,T,type,comp)	Specific isochoric heat capacity	$kJ/(kg \cdot K)$
$\eta = \mathrm{f}(p,t)$	Eta_ptcomp_HuGas	= eta_pTcomp_HuGas(p,T,type,comp)	Dynamic viscosity	$Pa \cdot s$
$h = \mathrm{f}(p,s)$	h_pscomp_HuGas	= h_pscomp_HuGas(p,s,type,comp)	Backward function: Specific enthalpy from pressure and entropy	kJ/kg
$h = \mathrm{f}(p,t)$	h_ptcomp_HuGas	= h_pTcomp_HuGas(p,T,type,comp)	Specific Enthalpy	kJ/kg
$h = \mathrm{f}(t,s)$	h_tscomp_HuGas	= h_Tscomp_HuGas(T,s,type,comp)	Backward function: Specific enthalpy from temperature and entropy	kJ/kg
$\kappa = \mathrm{f}(p,s)$	Kappa_pscomp_HuGas	= kappa_pscomp_HuGas(p,s,type,comp)	Backward function: Isentropic exponent from pressure and entropy	-

Function	Function Name	Call of Fortran Program	Property or Function	Unit
$\kappa = \mathrm{f}(p,t)$	Kappa_ptcomp_HuGas	= kappa_pTcomp_HuGas(p,T,type,comp)	Isentropic exponent	-
$\lambda = \mathrm{f}(p,t)$	Lambda_ptcomp_HuGas	= lambda_pTcomp_HuGas(p,T,type,comp)	Thermal conductivity	$\mathrm{W/(m \cdot K)}$
M	M_comp_HuGas	= M_comp_HuGas(type,comp)	Molar mass	kg/kmol
$\nu = \mathrm{f}(p,t)$	Ny_ptcomp_HuGas	= ny_pTcomp_HuGas(p,T,type,comp)	Kinematic viscosity	$\mathrm{m^2/s}$
$p = \mathrm{f}(h,s)$	p_hscomp_HuGas	= p_hscomp_HuGas(h,s,type,comp)	Backward function: Pressure from enthalpy and entropy	bar
$p = \mathrm{f}(t,s)$	p_tscomp_HuGas	= p_Tscomp_HuGas(T,s,type,comp)	Backward function: Pressure from temperature and entropy	bar
$p_{\mathrm{dsat}} = \mathrm{f}(p,t)$	pdsat_pt_HuGas	= pdsat_pT_HuGas(p,T)	Saturation pressure of water in mixture	bar
$\varphi = \mathrm{f}(p,t)$	Phi_ptcomp_HuGas	= phi_pTcomp_HuGas(p,T,type,comp)	Relative humidity	%
$\mathrm{Pr} = \mathrm{f}(p,t)$	Pr_ptcomp_HuGas	= Pr_pTcomp_HuGas(p,T,type,comp)	Prandtl number	-
$\psi_{\mathrm{wl}} = \mathrm{f}(p,t)$	Psiwl_ptcomp_HuGas	= psiwl_pTcomp_HuGas(p,T,type,comp)	Mole fraction of water (liquid)	kmol/kmol
$\psi_{\mathrm{wsat}} = \mathrm{f}(p,t)$	Psiwsat_ptcomp_HuGas	= psiwsat_pTcomp_HuGas(p,T,type,comp)	Mole fraction of water of the saturated gas	kmol/kmol
R	R_comp_HuGas	= R_comp_HuGas(type,comp)	Gas constant	$\mathrm{kJ/(kg \cdot K)}$
$Region = \mathrm{f}(h,s)$	Region_hscomp_HuGas	= Region_hscomp_HuGas(h,s,type,comp)	Region from given enthalpy and entropy	-
$Region = \mathrm{f}(p,h)$	Region_phcomp_HuGas	= Region_phcomp_HuGas(p,h,type,comp)	Region from given pressure and enthalpy	-
$Region = \mathrm{f}(p,s)$	Region_pscomp_HuGas	= Region_pscomp_HuGas(p,s,type,comp)	Region from given pressure and entropy	-

Function	Function Name	Call of Fortran Program	Property or Function	Unit
Region = f(p,t)	Region_ptcomp_HuGas	= Region_pTcomp_HuGas(p,T,type,comp)	Region from given pressure and temperature	-
Region = f(t,s)	Region_tscomp_HuGas	= Region_Tscomp_HuGas(T,s,type,comp)	Region from given temperature and entropy	-
$\rho = \mathrm{f}(p,t)$	Rho_ptcomp_HuGas	= rho_pTcomp_HuGas(p,T,type,comp)	Density	$\mathrm{kg/m^3}$
$s = \mathrm{f}(p,h)$	s_phcomp_HuGas	= s_phcomp_HuGas(p,h,type,comp)	Backward function: Specific entropy from pressure and specific enthalpy	$\mathrm{kJ/(kg \cdot K)}$
$s = \mathrm{f}(p,t)$	s_ptcomp_HuGas	= s_pTcomp_HuGas(p,T,type,comp)	Entropy	$\mathrm{kJ/(kg \cdot K)}$
$\sigma_\mathrm{w} = \mathrm{f}(t)$	Sigmaw_t_HuGas	= sigmaw_T_HuGas(T)	Surface tension of water	N/m
$t = \mathrm{f}(h,s)$	t_hscomp_HuGas	= T_hscomp_HuGas(h,s,type,comp)	Backward function: Temperature from enthalpy and entropy	°C
$t = \mathrm{f}(p,h)$	t_phcomp_HuGas	= T_phcomp_HuGas(p,h,type,comp)	Backward function: Temperature from pressure and enthalpy	°C
$t = \mathrm{f}(p,s)$	t_pscomp_HuGas	= T_pscomp_HuGas(p,s,type,comp)	Backward function: Temperature from pressure and entropy	°C
$t_\mathrm{w,dew} = \mathrm{f}(p)$	twdew_pcomp_HuGas	= Twdew_pcomp_HuGas(p,type,comp)	Dew point temperature of water	°C
$u = \mathrm{f}(p,t)$	u_ptcomp_HuGas	= u_pTcomp_HuGas(p,T,type,comp)	Specific internal energy	kJ/kg
$v = \mathrm{f}(h,s)$	v_hscomp_HuGas	= v_hscomp_HuGas(h,s,type,comp)	Backward function: Specific volume from enthalpy and entropy	$\mathrm{m^3/kg}$

Function	Function Name	Call of Fortran Program	Property or Function	Unit
$v = \mathrm{f}(p,h)$	v_phcomp_HuGas	= v_phcomp_HuGas(p,h,type,comp)	Backward function: Specific volume from pressure and enthalpy	m^3/kg
$v = \mathrm{f}(p,s)$	v_pscomp_HuGas	= v_pscomp_HuGas(p,s,type,comp)	Backward function: Specific volume from pressure and entropy	m^3/kg
$v = \mathrm{f}(p,t)$	v_ptcomp_HuGas	= v_pTcomp_HuGas(p,T,type,comp)	Specific volume	m^3/kg
$v = \mathrm{f}(t,s)$	v_tscomp_HuGas	= v_Tscomp_HuGas(T,s,type,comp)	Backward function: Specific volume from temperature and entropy	m^3/kg
$w = \mathrm{f}(p,t)$	w_ptcomp_HuGas	= w_pTcomp_HuGas(p,T,type,comp)	Isentropic speed of sound	m/s
x_w	xw_comp_HuGas	= xw_comp_HuGas(type,comp)	Humidity ratio (Absolute humidity)	g_{water}/kg_{gas}

Parameter

p	- Pressure *p* of mixture in bar
t	- Temperature *t* in °C
type	- Type of composition: type = 0 for compostion in mole fractions type = 1 for compostion in mass fractions
comp(1:8)	- Mole or mass fractions of components

Parameter for using Fortran Functions of LibHuGas

p	- Pressure *p* of mixture in bar
T	- Temperature *t* in °C

For input of composition in mass fractions use the function set_comp_mass_HuGas or

For input of composition in mole fractions use the function set_comp_mol_HuGas.

This composition will be stored in a Common Block and will be used for all calculations after that.

This will continue to occur unless the composition is changed by calling set_comp_mol_HuGas or set_comp_mass_HuGas again.

In order to know what composition is stored, it can be called by using get_comp_mass_HuGas or get_comp_mol_HuGas.

Range of Validity

Temperature:	*t* = - 70 °C ... 3026.15 °C
Pressure of mixture:	*p* = 0.01 bar ... 1000 bar

Mixture Components

Nr.	Symbol	Name of mixture component
0	Dummy	
1	Ar	Argon
2	Ne	Neon
3	N_2	Nitrogen
4	O_2	Oxygen
5	CO	Carbon Monoxide
6	CO_2	Carbon Dioxide
7	H_2O	Water
8	SO_2	Sulfur dioxide

Values of the Region Functions

Region	Description
0	Out of range of validity
1	Dry gas mixture
2	Unsaturated humid gas mixture
3	Liquid fog
4	Ice fog
5	Liquid-ice fog at 0.01 °C exactly
6	Pure liquid water
7	Pure water-wet steam
8	Pure steam
10	The CO2 in the gas mixture would be partly liquid. Calculation is terminated.
11	The SO2 in the gas mixture would be partly liquid. Calculation is terminated.

Reference States of LibHuGas

Fluid	t_0 [°C]	p_0 [bar]	h_0 [kJ/kg]	s_0 [kJ/(kg K)]	u_0 [kJ/kg]
Argon	0	1.01325	0	0	-56.79766
Neon	0	1.01325	0	0	-112.5436
Nitrogen	0	1.01325	0	0	-81.03459
Oxygen	0	1.01325	0	0	-70.90573
Carbon monoxide	0	1.01325	0	0	-81.08139
Carbon dioxide	0	1.01325	0	0	-51.25686
Water	0.01	0.00611657	$0.611872 \cdot 10^{-3}$	0	0
Sulfur dioxide	0	1.01325	0	0	-35.45001

Conversion to the Reference State of Water to t_0 = 0 °C

$$h = h_{\mathrm{HuGas}} - \xi_{\mathrm{H_2O}} \cdot 2500.914579 \text{ kJ/kg}$$

$$u = u_{\mathrm{HuGas}} - \xi_{\mathrm{H_2O}} \cdot 2500.914579 \text{ kJ/kg}$$

$$s = s_{\mathrm{HuGas}} - \xi_{\mathrm{H_2O}} \cdot 9.155493408 \text{ (kJ/kg K)}$$

Conversion to the Reference States of the Publications

$$z_{\mathrm{Publication}} = z_{\mathrm{LibHuGas}} + \Delta z \quad \text{where } z \equiv h,s,u$$

Fluid	t_0 [°C]	p_0 [bar]	Δh [kJ/kg]	Δs [kJ/(kg K)]	Δu [kJ/kg]	Reference
Argon	25	1.01325	-13.23564	$-4.6203961 \cdot 10^{-2}$	-13.23564	[27]
Neon	0	1.01325	0	0	0	-
Nitrogen	25	1.01325	283.2331	6.744095	283.2331	[28]
Oxygen	25	1	-23.20175	$-8.448914 \cdot 10^{-2}$	-23.20175	[29]
Carbon monoxide	0	1.01325	0	0	0	-
Carbon dioxide	25	1.01325	-21.90979	$-7.564382 \cdot 10^{-2}$	-21.90979	[30]
Water	0.01	0.00611657	0	0	0	[31]
Sulfur dioxide	0	1.01325	0	0	0	-

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 mixtures of real fluids from the LibHuGas property library.

2.1 Installing FluidLAB

Installing FluidLAB including LibHuGas for 32-bit MATLAB®

This section describes the installation of FluidLAB LibHuGas 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_LibHuGas.zip", you will see the folder

CD_FluidLAB_LibHuGas

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_LibHuGas_Docu_Eng.pdf
FluidLAB_LibHuGas_Setup.exe
LibHuGas.dll.

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

FluidLAB_LibHuGas_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\LibHuGas (for English version of Windows)
C:\Programme\FluidLAB\LibHuGas (for German version of Windows).

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

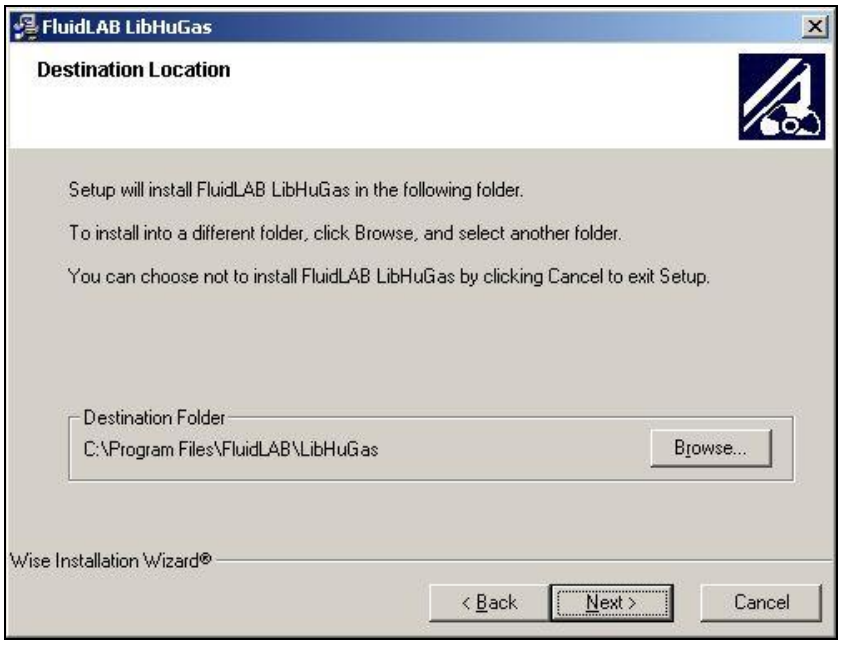

Figure 2.1: "Destination Location"

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 LibHuGas into the directory

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

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

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

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

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

Installing FluidLAB including LibHuGas for 64-bit MATLAB®

This section describes the installation of FluidLAB LibHuGas.

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_LibHuGas_x64.zip", you will see the folder

CD_FluidLAB_LibHuGas

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_LibHuGas_Docu_Eng.pdf
FluidLAB_LibHuGas_64_Setup.msi
LibHuGas.dll
Setup.exe.

and folders

/vcredist_x64
/WindowsInstaller3_1.

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

Setup.exe.

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

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

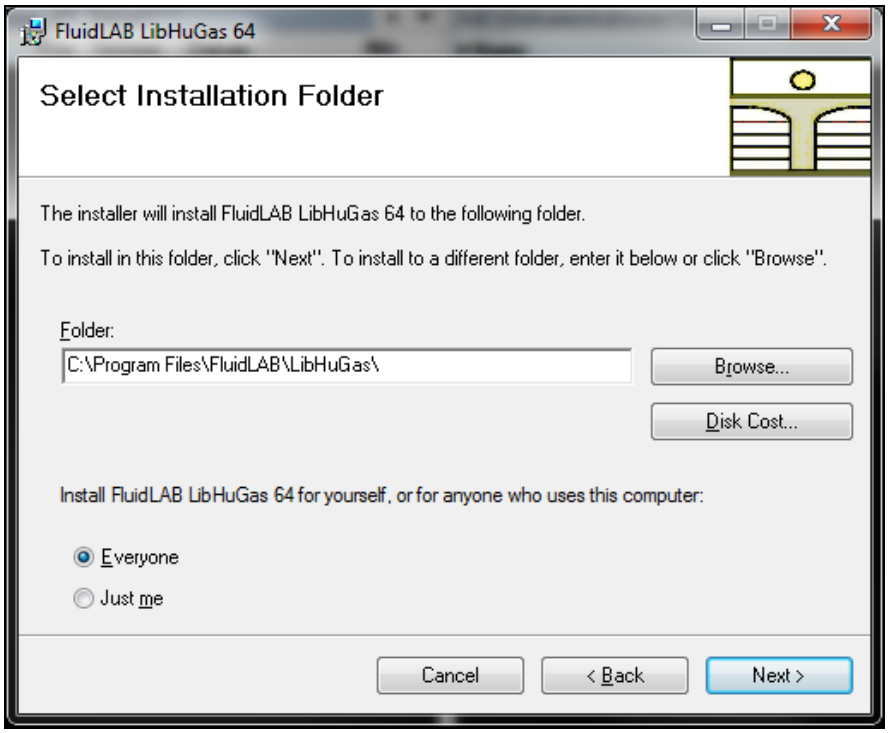

Figure 2.2: "Select Installation Folder"

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

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

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

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

Now, you have to overwrite the file "LibHuGas.dll" in your FluidLAB directory with the file of the same name provided in your CD folder with FluidLAB.
To do this, open the CD folder in "My Computer" and click on the file "LibHuGas.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\LibHuGas (for English version of Windows)
C:\Programme\FluidLAB\LibHuGas (for German version of Windows))

and insert the file "LibHuGas.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 "LibHuGas.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 LibHuGas into the directory

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

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

- MATLAB®-Interface-Programme for calculable functions

a_ptcomp_HuGas	R_comp_HuGas
cp_hscomp_HuGas	Region_hscomp_HuGas
cp_phcomp_HuGas	Region_phcomp_HuGas
cp_pscomp_HuGas	Region_pscomp_HuGas
cp_ptcomp_HuGas	Region_ptcomp_HuGas
cp_tscomp_HuGas	Region_tscomp_HuGas
cv_ptcomp_HuGas	Rho_ptcomp_HuGas
eta_ptcomp_HuGas	s_phcomp_HuGas
h_pscomp_HuGas	s_ptcomp_HuGas
h_ptcomp_HuGas	Sigmaw_t_HuGas
h_tscomp_HuGas	t_hscomp_HuGas
Kappa_ptcomp_HuGas	t_phcomp_HuGas
Lambda_ptcomp_HuGas	t_pscomp_HuGas
M_comp_HuGas	twdew_pcomp_HuGas
Ny_ptcomp_HuGas	u_ptcomp_HuGas
p_hscomp_HuGas	v_hscomp_HuGas
p_tscomp_HuGas	v_phcomp_HuGas
pdsat_pt_HuGas	v_pscomp_HuGas
Phi_ptcomp_HuGas	v_ptcomp_HuGas
Pr_ptcomp_HuGas	v_tscomp_HuGas
Psiwl_ptcomp_HuGas	w_ptcomp_HuGas
Psiwsat_ptcomp_HuGas	xw_comp_HuGas

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 LibHuGas directory (the standard being

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

2.2 Licensing the LibHuGas 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 LibHuGas (see figure below).

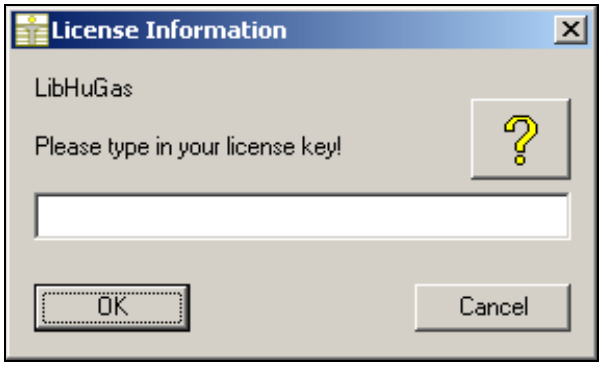

Figure 2.3: "License Information" window

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:

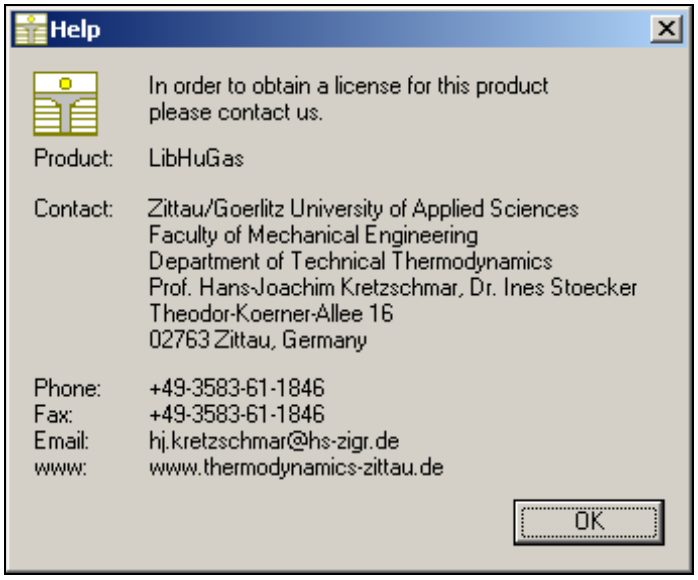

Figure 2.4: "Help" window

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

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

2.3 Example: Calculation of the Enthalpy $h = f(p, t, \psi 1 \ldots \psi 8)$ of the Gas Mixture in an M-File

Now we will calculate, step by step, the enthalpy h as a function of the mixture pressure p, temperature t and a composition vector $\psi_1 \ldots \psi_8$ 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 "\LibHuGas"; in the standard case:

  "C:\Program Files\FluidLAB" (for English version of Windows)
  "C:\Programme\FluidLAB" (for German version of Windows)
- Create the folder "\LibHuGas_Example". Click "File", then click "New" in the menu that appears and afterwards select "Folder". Name the new folder "\LibHuGas_Example".
- You will see the following window:

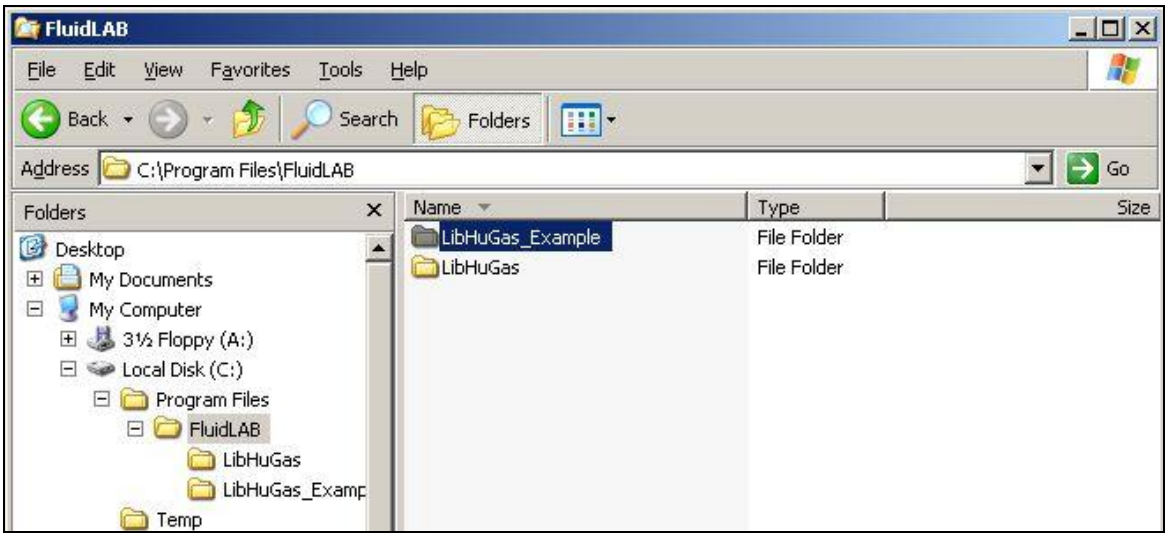

Figure 2.5: Folders "LibHuGas" and "LibHuGas_Example"

- Switch into the directory "\LibHuGas" within "\FluidLAB", in the standard being:
  "C:\Program Files\FluidLAB\LibHuGas" (for English version of Windows)
  "C:\Programme\FluidLAB\LibHuGas" (for German version of Windows)

- You will see the following window:

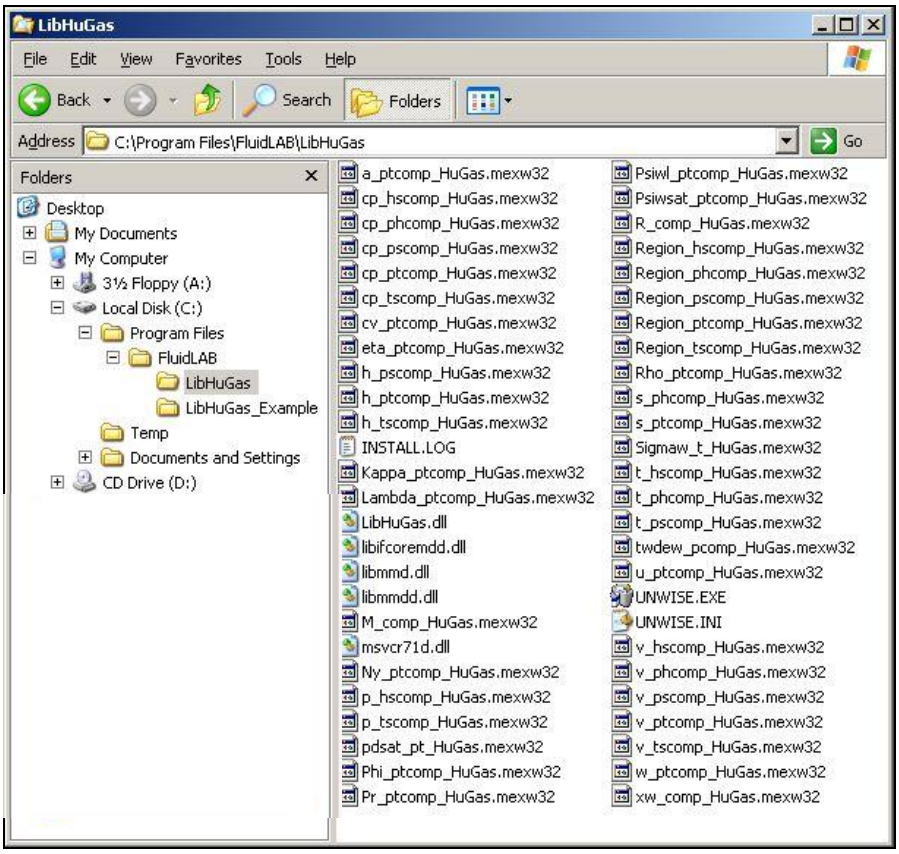

Figure 2.6: Contents of the folder "LibHuGas"

You will now have to copy the necessary files following into the directory

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

in order to calculate the function $h = f(p, t, \psi_1 \ldots \psi_8)$.

- The following files are necessary:
  - "h_ptcomp_HuGas.mexw32"
  - "LibHuGas.dll"
  - "libifcoremdd.dll"
  - "libmmd.dll"
  - "libmmdd.dll"
  - "msvcr71d.dll"
- Click the file "h_ptcomp_HuGas.mexw32", then click "Edit" in the upper menu bar and select "Copy".
- Switch into the directory

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

  click "Edit" and select "Paste".
- Repeat these steps in order to copy the other files listed above.

- You will see the following window:

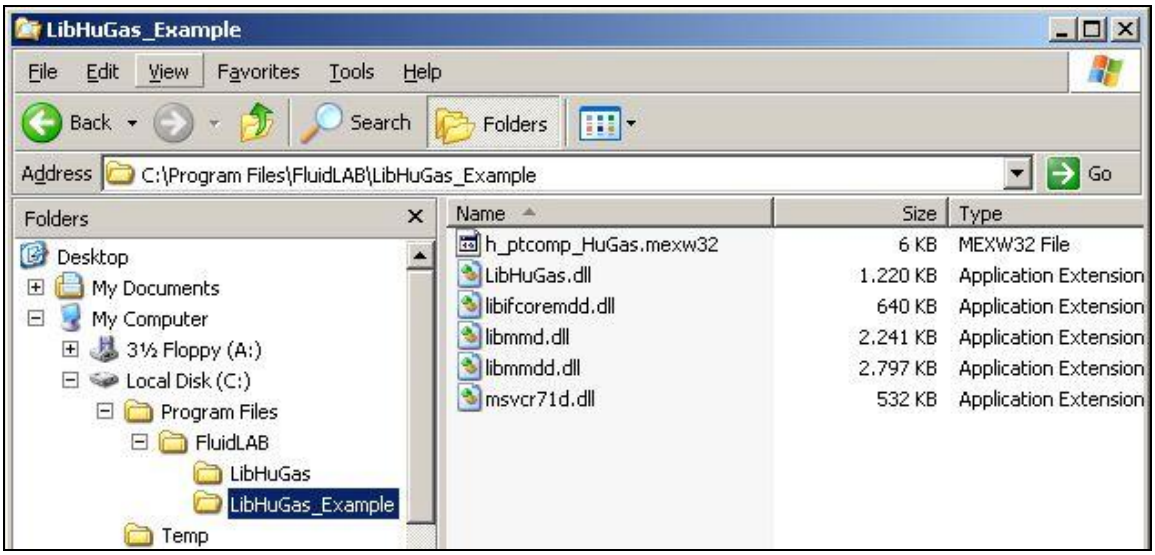

Figure 2.7: Contents of the folder "LibHuGas_Example"

If you have installed the 64-bit version of LibHuGas you will now have to copy the following files into the directory

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

in order to calculate the function $h = f(p,t,\xi_1 \ldots \xi_{10})$.

- The following six files are needed:
  - "h_ptcomp_HuGas.mexw64"
  - "LC.dll"
  - "LibHuGas.dll"
  - "libifcoremd.dll"
  - "libiomp5.dll"
  - "libmmd.dll."
- Click the file "h_ptcomp_HuGas.mexw64", then click "Edit" in the upper menu bar and select "Copy."
- Switch into the directory

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

  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 figure in order to open the folder "\LibHuGas_Example" in the window "Current Directory".

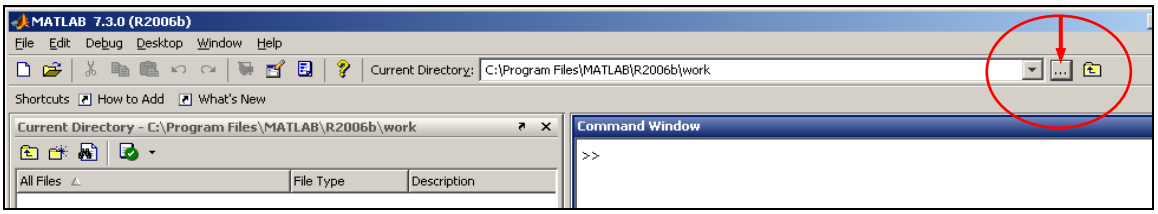

Figure 2.8: Selection of the working directory

- Search and click the directory "C:\Program Files\FluidLAB\LibHuGas_Example" in the menu that appears (see figure below).

Figure 2.9: Choosing the "LibHuGas_Example" folder

- Confirm your selection by clicking the "OK" button.
- First of all you need to create an M–File in MATLAB. Click "File" within MATLAB, 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.

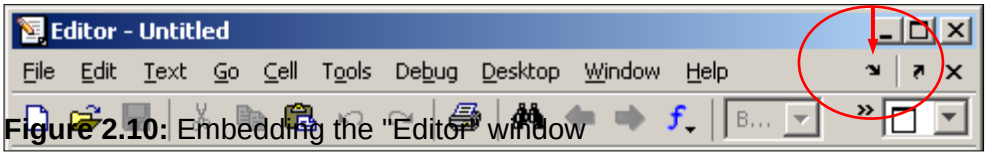

Figure 2.10: Embedding the "Editor" window

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

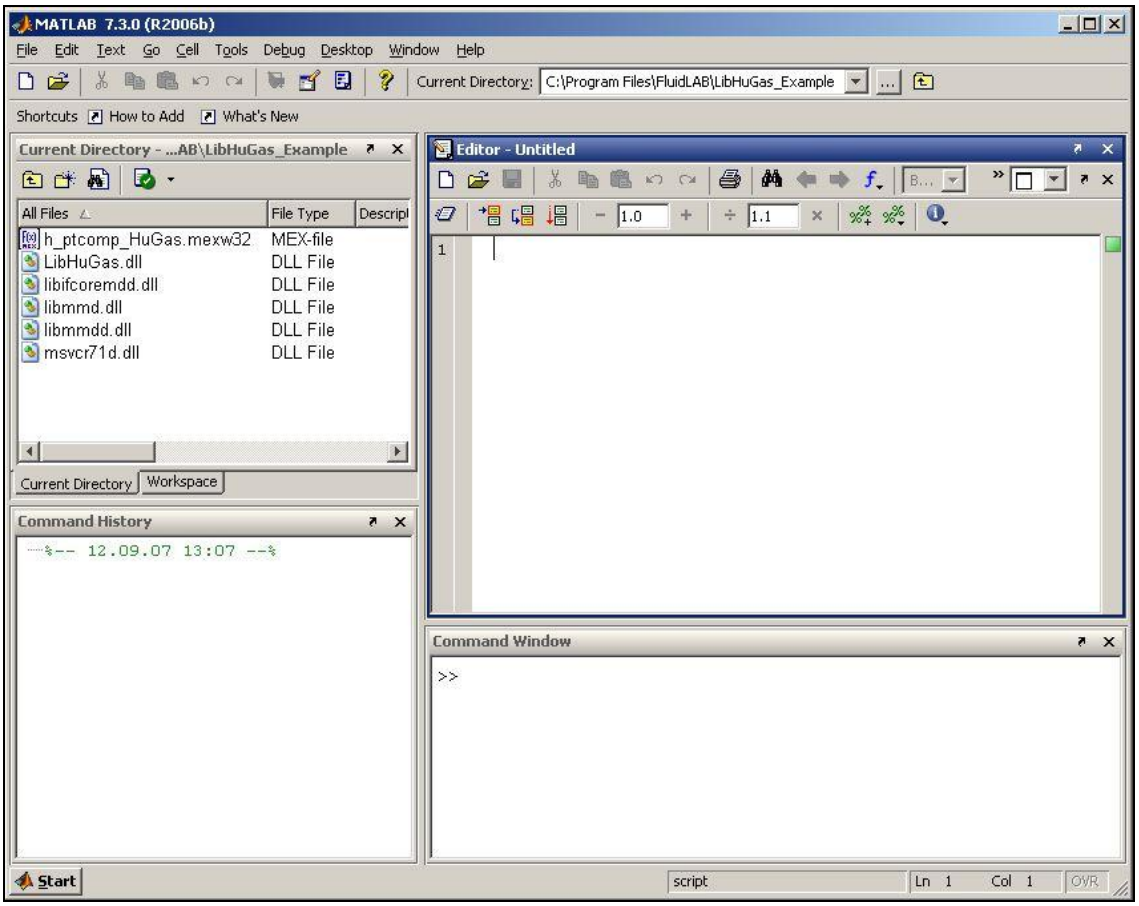

Figure 2.11: Embedded "Editor" window

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

Text to be written:	Explanation:
`% h_ptcomp_HuGas.m`	file name as comment
`%%`	paragraph separation
`p=10; % pressure in bar`	declaration of the variables pressure, temperature, art and composition of mixture
`t=500; % temperature in °C`	
`art=0; % input values in mole fractions`	
`Psi=[0.0088 0 0.7480 0.1352 0 0.0330 0.0750 0] % composition`	
`%%`	paragraph separation
`h=h_ptcomp_HuGas(p,t,art,Psi)`	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 = 10 bar
  (Range of validity: p = 0.01 bar ... 1000 bar)
- Second operand: Value for t = 500 °C
  (Range of validity: t = - 70 °C ... 3026.85 °C)
- Third operand: Value for *art* = 0
  (Chose between: art = 1 for input in mass fractions $\xi_1 \ldots \xi_8$
  art = 0 for input in mole fractions, i.e. volume fractions $\psi_1 \ldots \psi_8$)
- Fourth operand: Vector for the composition Psi (see above).

In the following you can see the single values which the vector for the composition Psi consists of:

ψ_1	for Argon	Ar	⇒ the value 0.0088
ψ_2	for Neon	Ne	⇒ the value 0
ψ_3	for Nitrogen	N_2	⇒ the value 0.7480
ψ_4	for Oxygen	O_2	⇒ the value 0.1352
ψ_5	for Carbon monoxide	CO	⇒ the value 0
ψ_6	for Carbon dioxide	CO_2	⇒ the value 0.0330
ψ_7	for Water	H_2O	⇒ the value 0.0750
ψ_8	for Sulfur dioxide	SO_2	⇒ the value 0

- Save the "M-File" by clicking the "File" button and then click "Save As...".
- The menu "Save file as:" appears; therein the folder name "LibHuGas_Example" must be displayed next to "Save in:"
- Next to "File name" you have to type in "Example_h_ptcomp_HuGas.m" and afterwards click the "Save" button.
- You will see the following window:

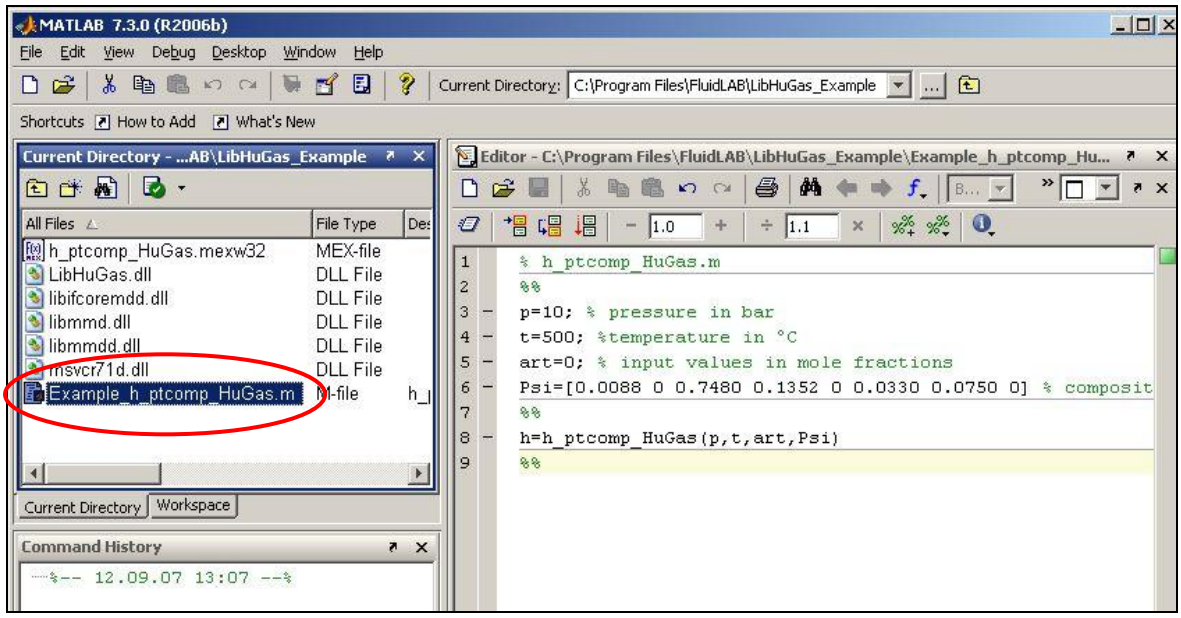

Figure 2.12: "Example_h_ptcomp_HuGas.m" M-file

- The file "Example_h_ptcomp_HuGas.m" appears within the "Current Directory" window.
- Right-click this file and click "Run" in the menu which appears (see figure below).

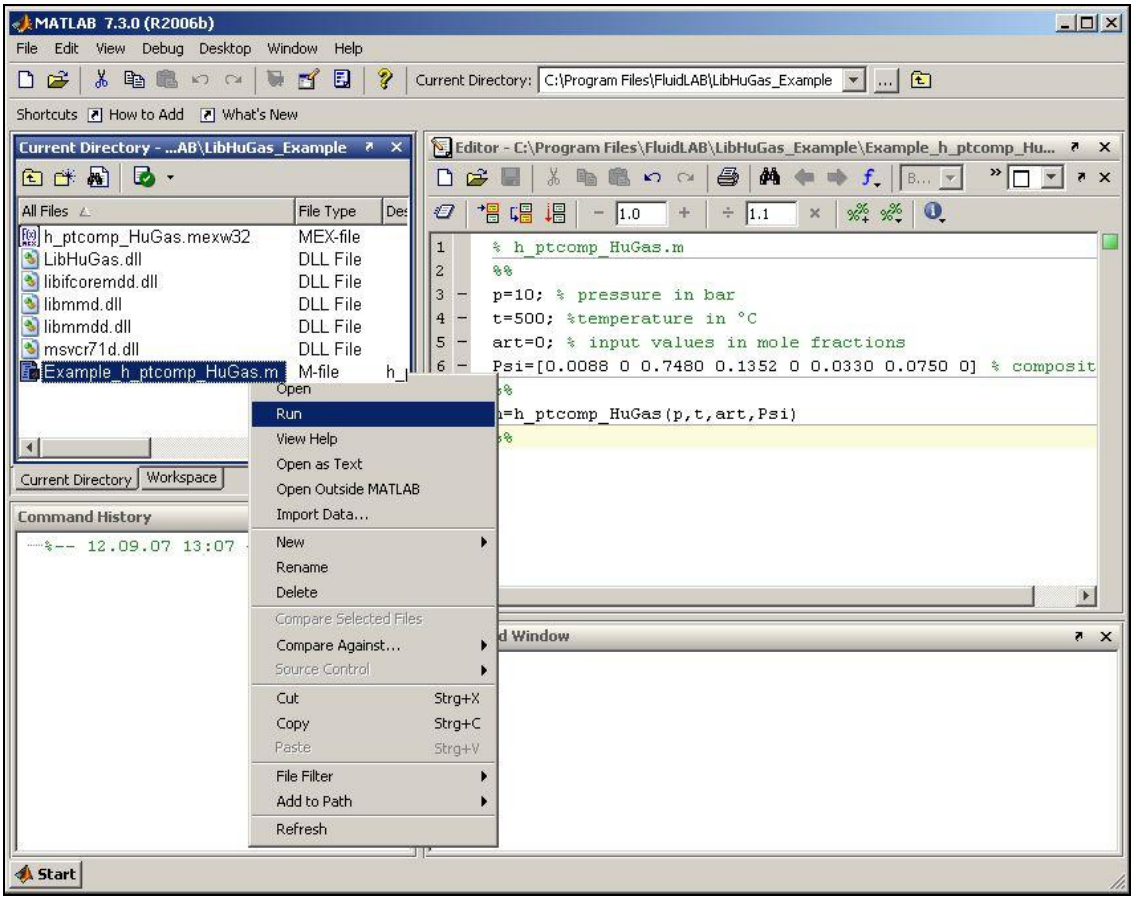

Figure 2.13: Running the "Example_h_ptcomp_HuGas.m" M-file

- You will see the following window:

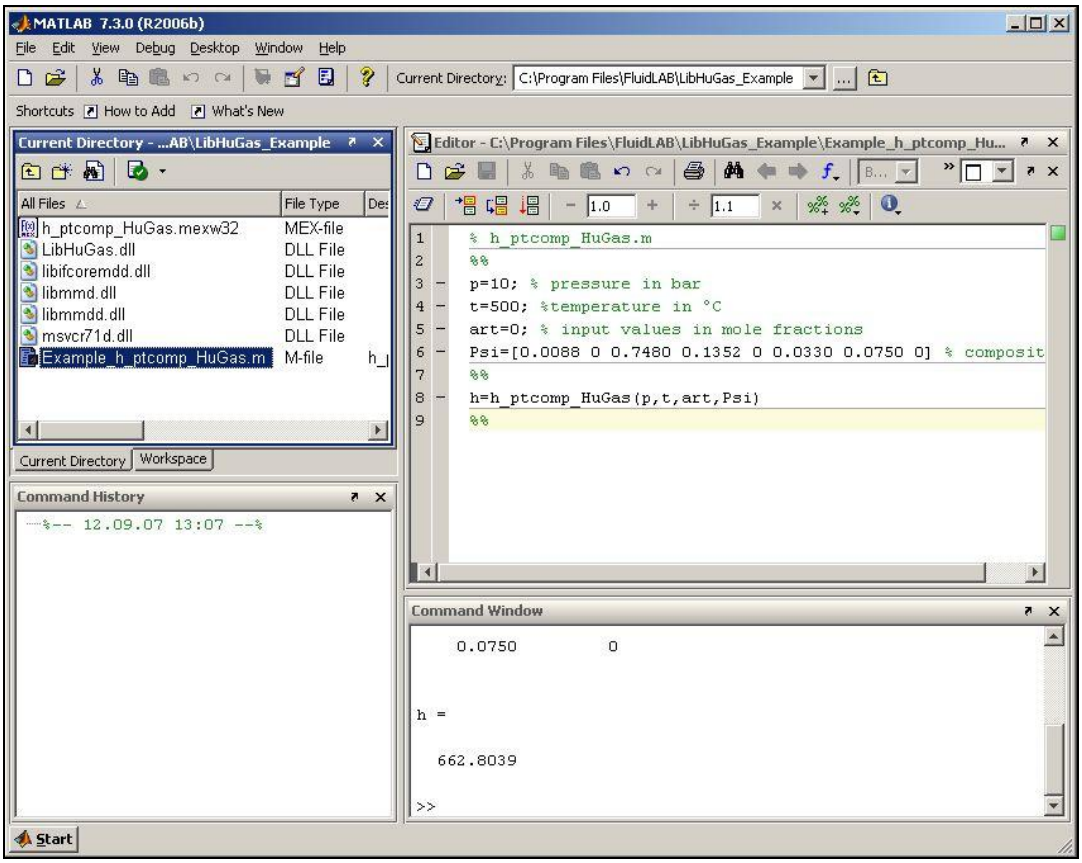

Figure 2.14: MATLAB® with calculated result

In the "Command Window" you will see the result "h = 662.8039". The corresponding unit is kJ/kg (see table of the property functions in chapter 1).

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

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

and you may use it as a basis for further calculations with FluidLAB.

2.4 Example: Calculation of the Enthalpy $h = f(p, t, \psi_1 \ldots \psi_8)$ of the Gas Mixture 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 "\LibHuGas_Example" in the window "Current Directory.

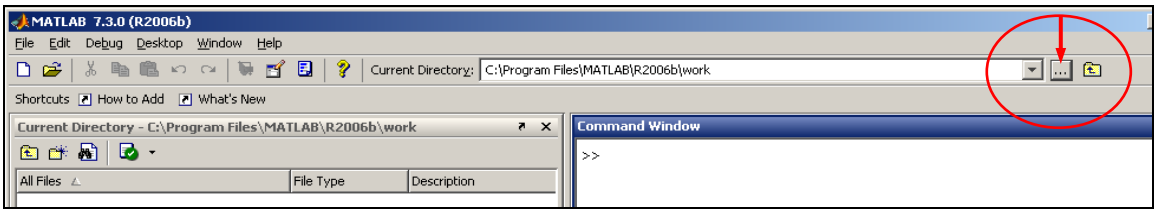

Figure 2.15: Selection of the working directory

- Search and click the directory

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

  in the menu that appears (see figure below).

Figure 2.16: Choosing the "LibHuGas_Example" folder

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

- You will see the following window:

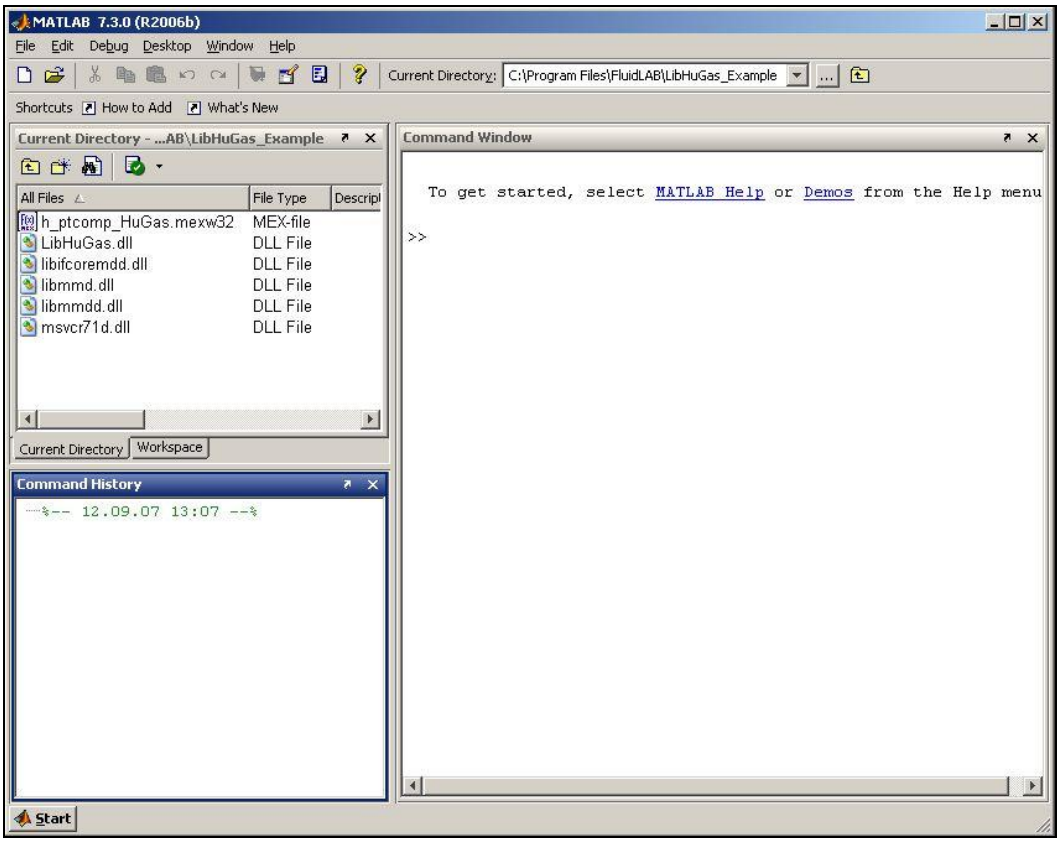

Figure 2.17: MATLAB® with necessary files

Corresponding to the table of property functions in Chapter 1 you have to call the function "h_ptcomp_HuGas" as follows for calculating h = f(p, t, (1 ... 8)):

Enter the composition vector as follows:

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

- Type "Psi = [0.0088 0 0.7480 0.1352 0 0.0330 0.0750 0]" and press the "ENTER" button.

In the following you can see the single values which the vector for the composition Psi consists of:

ψ_1	for Argon	Ar	$\Rightarrow$ the value 0.0088
ψ_2	for Neon	Ne	$\Rightarrow$ the value 0
ψ_3	for Nitrogen	N_2	$\Rightarrow$ the value 0.7480
ψ_4	for Oxygen	O_2	$\Rightarrow$ the value 0.1352
ψ_5	for Carbon monoxide	CO	$\Rightarrow$ the value 0
ψ_6	for Carbon dioxide	CO_2	$\Rightarrow$ the value 0.0330
ψ_7	for Water	H_2O	$\Rightarrow$ the value 0.0750
ψ_8	for Sulfur dioxide	SO_2	$\Rightarrow$ the value 0

- Type "h=h_ptcomp_HuGas(10,500,0,Psi)" within the "Command Window".

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

- First operand: Value for p = 10 bar
  (Range of validity: p = 0.01 bar ... 1000 bar)
- Second operand: Value for t = 500 °C
  (Range of validity: t = - 70 °C ... 3026.85 °C)
- Third operand: Value for *art* = 0
  (Chose between: art = 1 for input in mass fractions $\xi_1 \ldots \xi_8$
  art = 0 for input in mole fractions, i.e. volume fractions $\psi_1 \ldots \psi_8$)
- Fourth operand: Vector for the composition Psi (see above).

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

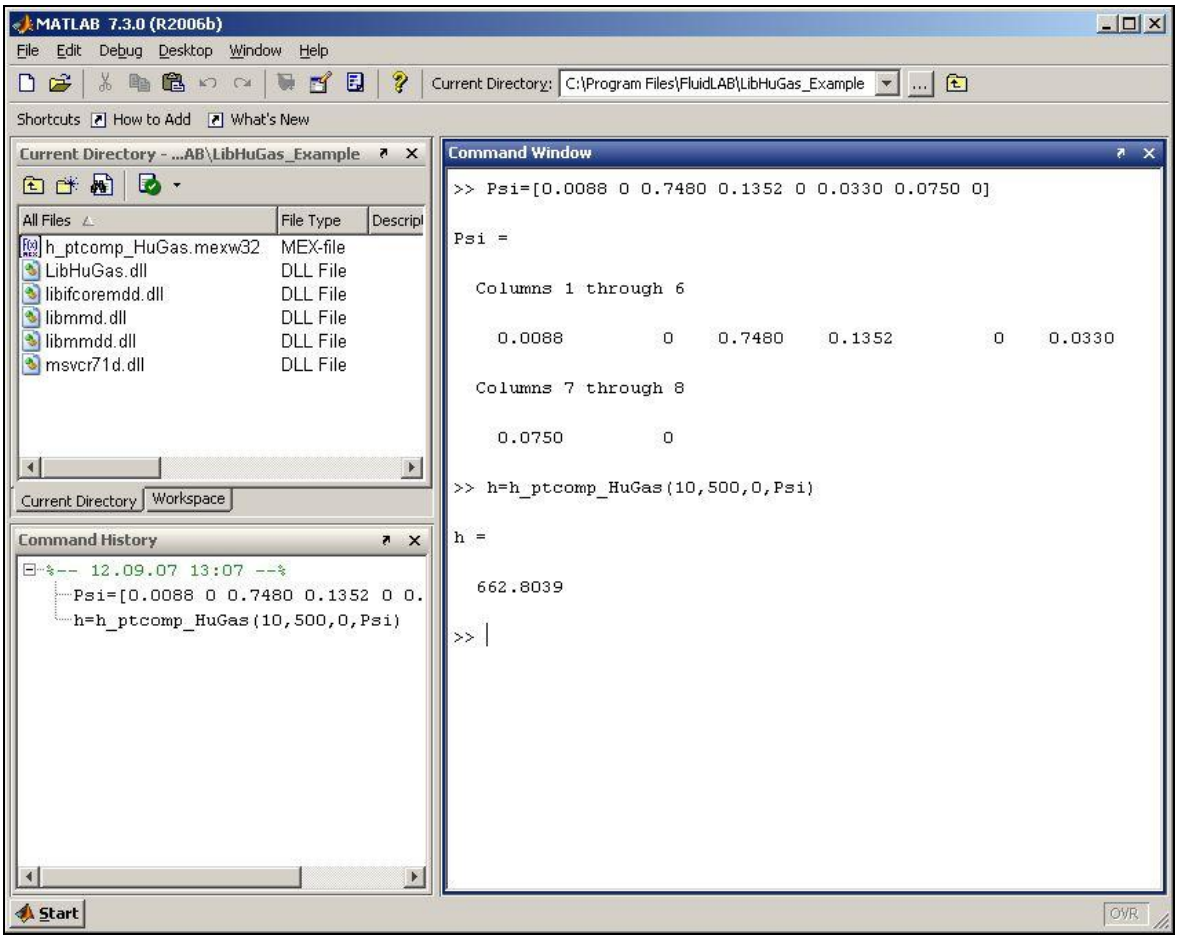

Figure 2.18: MATLAB® with calculated result

In the "Command Window" you will see the result "h = 662.8039". The corresponding unit is kJ/kg (see table of the property functions in Chapter 1).

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

2.5 Removing LibHuGas in FluidLAB

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

3. Program Documentation

Thermal Diffusivity *a* = f(*p*,*t*,type,comp(1:8))

Function Name:

a_ptcomp_HuGas

Input values:

p - Pressure *p* in bar

t - Temperature *t* in °C

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

a_ptcomp_HuGas - Thermal diffusivity in m^2/s

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

- Thermal diffusivity $a = \frac{\lambda}{\rho \cdot c_p}$, model of ideal mixture of real fluids

- Valid only for unsaturated humid gas ($\psi_w \leq \psi_{w,sat}$)

Result for incorrect input values:

$$a_ptcomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	ρ, c_p - ideal part	ρ, c_p - real part	λ
Ar	[26]	[27]	[33]
Ne	[26]	-	[34],[35],[40],[41]
N_2	[26]	[28]	[42]
O_2	[26]	[29]	[37]
CO	[26]	-	[38]
CO_2	[26]	[30]	[43]
H_2O	[26]	[31]	[16]
SO_2	[26]	-	[34],[35],[40]

Specific Isobaric Heat Capacity c_p = f(h,s,type,comp(1:8))

Function Name:

cp_hscomp_HuGas

Input values:

h - Specific enthalpy h in kJ/kg

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

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - vector of composition (Ar ,Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

cp_hscomp_HuGas - specific isobaric heat capacity in kJ/(kg K)

Range of validity:

Temperature t : - 70 °C $\leq$ t $\leq$ 3026.85 °C

Pressure p: 0.01 bar $\leq$ p $\leq$ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of p and t from h(p,t,comp) and s(p,t,comp) and calculation of c_p from c_p(p,t,comp)

Calculation:

- Valid only for unsaturated humid gas ($\psi_w \leq \psi_{w,sat}$)

- Effects of dissociation are considered for temperatures greater than 500 °C

Result for incorrect input values:

$$\text{cp_hscomp_HuGas} = -1 \cdot 10^{100}$$

Reference:

Gas	c_p,h,s - ideal part	c_p,h,s - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Specific Isobaric Heat Capacity c_p = f(p,h,type,comp(1:8))

Function Name:

cp_phcomp_HuGas

Input values:

p - Pressure p in bar

h - Specific enthalpy h in kJ/kg

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

cp_phcomp_HuGas - specific isobaric heat capacity in kJ/(kg K)

Range of validity:

Temperature t : - 70 °C $\leq$ t $\leq$ 3026.85 °C

Pressure p: 0.01 bar $\leq$ p $\leq$ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of t from h(p,t,comp) and calculation of c_p from c_p(p,t,comp)

Calculation:

- Valid only for unsaturated humid gas ($\psi_w \leq \psi_{w,sat}$)

- Effects of dissociation are considered for temperatures greater than 500 °C

Result for incorrect input values:

$$\text{cp_phcomp_HuGas} = -1 \cdot 10^{100}$$

Reference:

Gas	c_p,h - ideal part	c_p,h - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Specific Isobaric Heat Capacity c_p = f(p,s,type,comp(1:8))

Function Name:

cp_pscomp_HuGas

Input values:

p - Pressure p in bar

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

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

cp_pscomp_HuGas - specific isobaric heat capacity in kJ/(kg K)

Range of validity:

Temperature t : - 70 °C $\leq$ t $\leq$ 3026.85 °C

Pressure p: 0.01 bar $\leq$ p $\leq$ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of t from s(p,t,comp) and calculation of c_p from c_p(p,t,comp)

Calculation:

- Valid only for unsaturated humid gas ($\psi_w \leq \psi_{w,sat}$)
- Effects of dissociation are considered for temperatures greater than 500 °C

Result for incorrect input values:

$$\text{cp_pscomp_HuGas} = -1 \cdot 10^{100}$$

Reference:

Gas	c_p,s - ideal part	c_p,s - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Specific Isobaric Heat Capacity c_p = f(p,t,type,comp(1:8))

Function Name:

cp_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

cp_ptcomp_HuGas - specific isobaric heat capacity in kJ/(kg K)

Range of validity:

Temperature t : - 70 °C $\leq$ t $\leq$ 3026.85 °C

Pressure p: 0.01 bar $\leq$ p $\leq$ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

- Valid only for unsaturated humid gas ($\psi_w \leq \psi_{w,sat}$)
- Effects of dissociation are considered for temperatures greater than 500 °C

Result for incorrect input values:

$$\text{cp_ptcomp_HuGas} = -1 \cdot 10^{100}$$

Reference:

Gas	c_p - ideal part	c_p - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Specific Isobaric Heat Capacity c_p = f(t,s,type,comp(1:8))

Function Name:

cp_tscomp_HuGas

Input values:

t - Temperature t in °C

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

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

cp_tscomp_HuGas - specific isobaric heat capacity in kJ/(kg K)

Range of validity:

Temperature t : - 70 °C $\leq$ t $\leq$ 3026.85 °C

Pressure p: 0.01 bar $\leq$ p $\leq$ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of p from s(p,t,comp) and calculation of c_p from c_p(p,t,comp)

Calculation:

- Valid only for unsaturated humid gas ($\psi_w \leq \psi_{w,sat}$)
- Effects of dissociation are considered for temperatures greater than 500 °C

Result for incorrect input values:

$$\text{cp_tscomp_HuGas} = -1 \cdot 10^{100}$$

Reference:

Gas	c_p,s - ideal part	c_p,s - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Specific Isochoric Heat Capacity c_v = f(p,t,type,comp(1:8))

Function Name:

cv_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

cv_ptcomp_HuGas - Specific isochoric heat capacity in kJ/(kg K)

Range of validity:

Temperature t : - 70 °C $\leq$ t $\leq$ 3026.85 °C

Pressure p: 0.01 bar $\leq$ p $\leq$ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

- Valid only for unsaturated humid gas ($\psi_w \leq \psi_{w,sat}$)
- Effects of dissociation are considered for temperatures greater than 500 °C

Result for incorrect input values:

$$cv_ptcomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	c_v - ideal part	c_v - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Dynamic Viscosity η = f(p,t,type,comp(1:8))

Function Name:

Eta_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Eta_ptcomp_HuGas - Dynamic viscosity in Pa s

Range of validity:

Temperature t : - 70 °C $\leq$ t $\leq$ 3026.85 °C

Pressure p: 0.01 bar $\leq$ p $\leq$ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for liquid fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water
- for ice fog ($\psi_w > \psi_{w,sat}$, t < 0.01 °C) as saturated humid gas mixture

Result for incorrect input values:

$$\text{Eta_ptcomp_HuGas} = -1 \cdot 10^{100}$$

Reference:

Gas	η
Ar	[33]
Ne	[34]
N_2	[36]
O_2	[37]
CO	[38]
CO_2	[39]
H_2O	[17]
SO_2	[34]

Specific Enthalpy *h* = f(*p*,*s*,type,comp(1:8))

Function Name:

h_pscomp_HuGas

Input values:

p - Pressure *p* in bar

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

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

h_pscomp_HuGas - specific enthalpy in kJ/kg

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *t* from s(p,t,comp) and calculation of *h* from h(p,t,comp)

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice
- Effects of dissociation are considered for temperatures greater than 500 °C

Result for incorrect input values:

$$h_pscomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	*h*,*s* - ideal part	*h*,*s* - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N_2	[26]	[28]	-
O_2	[26]	[29]	-
CO	[26]	-	-
CO_2	[26]	[30]	-
H_2O	[26]	[31]	[25]
SO_2	[26]	-	-

Specific Enthalpy *h* = f(*p*,*t*,type,comp(1:8))

Function Name:

h_ptcomp_HuGas

Input values:

p - Pressure *p* in bar

t - Temperature *t* in °C

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

h_ptcomp_HuGas - Specific enthalpy in kJ/kg

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice
- Effects of dissociation are considered for temperatures greater than 500 °C

Result for incorrect input values:

$$h_ptcomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	*h* - ideal part	*h* - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N_2	[26]	[28]	-
O_2	[26]	[29]	-
CO	[26]	-	-
CO_2	[26]	[30]	-
H_2O	[26]	[31]	[25]
SO_2	[26]	-	-

Specific Enthalpy *h* = f(*t*,*s*,type,comp(1:8))

Function Name:

h_tscomp_HuGas

Input values:

t - Temperature *t* in °C

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

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

h_tscomp_HuGas - Specific enthalpy in kJ/kg

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *p* from s(p,t,comp) and calculation *h* from h(p,t,comp)

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real gases (dry gas and steam)
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice, calculation is not possible for liquid-ice fog at 0.01 °C
- Effects of dissociation are considered for temperatures greater than 500 °C

Result for incorrect input values:

$$h_tscomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	*h*,*s* ideal part	*h*,*s* real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N_2	[26]	[28]	-
O_2	[26]	[29]	-
CO	[26]	-	-
CO_2	[26]	[30]	-
H_2O	[26]	[31]	[25]
SO_2	[26]	-	-

Isentropic Exponent κ = f(p,t,type,comp(1:8))

Function Name:

Kappa_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Kappa_ptcomp_HuGas - Isentropic exponent

Range of validity:

Temperature t : - 70 °C $\leq$ t $\leq$ 3026.85 °C

Pressure p: 0.01 bar $\leq$ p $\leq$ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$):

$$\kappa = -\frac{v}{p} \cdot \left(\frac{\partial p}{\partial v}\right)_T \cdot \frac{c_p}{c_v}$$

- for liquid fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water

- for ice fog ($\psi_w > \psi_{w,sat}$, t < 0.01 °C) as saturated humid gas mixture

Result for incorrect input values:

$$\text{kappa_ptcomp_HuGas} = -1 \cdot 10^{100}$$

Reference:

Gas	v, c_p, c_v - ideal part	v, c_p, c_v - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Isentropic Exponent κ = f(*p*,*s*,type,comp(1:8))

Function Name:

Kappa_pscomp_HuGas

Input values:

p - Pressure *p* in bar

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

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Kappa_pscomp_HuGas - Isentropic exponent

Range of validity:

Temperature *t* : - 70 °C $\leq$ *t* $\leq$ 3026.85 °C

Pressure *p*: 0.01 bar $\leq$ *p* $\leq$ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *t* from s(p,t,comp) and calculation of κ from kappa(p,t,comp) :

- for unsaturated and saturated humidity gas ($\psi_w \leq \psi_{w,sat}$)

$$\kappa = -\frac{v}{p} \cdot \left(\frac{\partial p}{\partial v}\right)_T \cdot \frac{c_p}{c_v}$$

- for liquid fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water

- for ice fog ($\psi_w > \psi_{w,sat}$, *t* < 0.01 °C) as saturated humid gas mixture

Result for incorrect input values:

$$\text{kappa_pscomp_HuGas} = -1 \cdot 10^{100}$$

Reference:

Gas	*v*, c_p, c_v - ideal part	*v*, c_p, c_v - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Thermal Conductivity λ = f(p,t,type,comp(1:8))

Function Name:

Lambda_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Lambda_ptcomp_HuGas - Thermal conductivity in W/(m K)

Range of validity:

Temperature t : - 70 °C $\leq$ t $\leq$ 3026.85 °C

Pressure p: 0.01 bar $\leq$ p $\leq$ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for liquid fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water
- for ice fog ($\psi_w > \psi_{w,sat}$, t < 0.01 °C) as saturated humid gas mixture

Result for incorrect input values:

$$\text{lambda_ptcomp_HuGas} = -1 \cdot 10^{100}$$

Reference:

Gas	λ
Ar	[33]
Ne	[34],[35],[40],[41]
N_2	[42]
O_2	[37]
CO	[38]
CO_2	[43]
H_2O	[16]
SO_2	[34],[35],[40]

Molar Mass *M* = f(type,comp(1:8))

Function Name:

M_comp_HuGas

Input values:

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

M_comp_HuGas - Molar mass in kg/kmol

Result for incorrect input values:

$$M_comp_HuGas = -1 \cdot 10^{100}$$

Kinematic Viscosity ν = f(p,t,type,comp(1:8))

Function Name:

Ny_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Ny_ptcomp_HuGas - Kinematic viscosity in m^2/s

Range of validity:

Temperature t : - 70 °C $\leq$ t $\leq$ 3026.85 °C

Pressure p: 0.01 bar $\leq$ p $\leq$ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

- Kinematic viscosity $\nu = \frac{\eta}{\rho} = \eta \cdot v$
- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for liquid fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water
- for ice fog ($\psi_w > \psi_{w,sat}$, t < 0.01 °C) as saturated humid gas mixture

Result for incorrect input values:

$$\text{Ny_ptcomp_HuGas} = -1 \cdot 10^{100}$$

Reference:

Gas	v - ideal part	v - real part	λ
Ar	[26]	[27]	[33]
Ne	[26]	-	[34],[35],[40],[41]
N_2	[26]	[28]	[42]
O_2	[26]	[29]	[37]
CO	[26]	-	[38]
CO_2	[26]	[30]	[43]
H_2O	[26]	[31]	[16]
SO_2	[26]	-	[34],[35],[40]

Pressure *p* = f(*h*,*s*,type,comp(1:8))

Function Name:

p_hscomp_HuGas

Input values:

h - Specific enthalpy *h* in kJ/kg

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

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

p_hscomp_HuGas - Pressure in bar

Range of validity:

Temperature *t* : - 70 °C $\leq$ *t* $\leq$ 3026.85 °C

Pressure *p*: 0.01 bar $\leq$ *p* $\leq$ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *t* and *p* from h(p,t,comp) and s(p,t,comp) and calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real gases (dry gas and steam)
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice, calculation is not possible for liquid-ice fog at 0.01 °C
- Effects of dissociation are considered for temperatures greater than 500 °C

Result for incorrect input values:

$$p_hscomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	*h*, *s* - ideal part	*h*, *s* - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N_2	[26]	[28]	-
O_2	[26]	[29]	-
CO	[26]	-	-
CO_2	[26]	[30]	-
H_2O	[26]	[31]	[25]
SO_2	[26]	-	-

Pressure *p* = f(*t*,*s*,type,comp(1:8))

Function Name:

p_tscomp_HuGas

Input values:

t - Temperature *t* in °C

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

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

p_tscomp_HuGas - Pressure in bar

Range of validity:

Temperature *t* : - 70 °C $\leq$ *t* $\leq$ 3026.85 °C

Pressure *p*: 0.01 bar $\leq$ *p* $\leq$ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *p* from s(p,t,comp) and calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real gases (dry gas and steam)
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice, calculation is not possible for liquid-ice fog at 0.01 °C
- Effects of dissociation are considered for temperatures greater than 500 °C

Result for incorrect input values:

$$p_tscomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	*s* - ideal part	*s* - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N_2	[26]	[28]	-
O_2	[26]	[29]	-
CO	[26]	-	-
CO_2	[26]	[30]	-
H_2O	[26]	[31]	[25]
SO_2	[26]	-	-

Saturation Pressure of Water p_{dsat} = f(p,t)

Function Name:

pdsat_pt_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

Result:

pdsat_pt_HuGas - Saturation pressure of water in bar

Range of validity:

Temperature t : - 70 °C $\leq$ t $\leq$ 3026.85 °C

Pressure p: 0.01 bar $\leq$ p $\leq$ 1000 bar

Comments:

$p_{dsat}(p,t)$ for $t \geq$ 0.01 °C – Vapour pressure of water in gas mixtures

for $t <$ 0.01 °C – Sublimation pressure of water in gas mixtures

Result for incorrect input values:

$$\text{pdsat_pt_HuGas} = -1 \cdot 10^{100}$$

Reference:

$p_{dsat}(p,t)$ for $t \geq$ 0.01 °C from IAPWS-IF97 [1], [2], [3], [4]

$p_{dsat}(p,t)$ for $t <$ 0.01 °C from IAPWS-92 [24]

Relative Humidity φ = f(p,t,type,comp(1:8))

Function Name:

Phi_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Phi_ptcomp_HuGas - Relative humidity in %

Range of validity:

Temperature t : - 70 °C $\leq$ t $\leq$ 3026.85 °C

Pressure p: 0.01 bar $\leq$ p $\leq$ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Relative humidity $\varphi = \dfrac{x_\mathrm{w}}{\dfrac{R_\mathrm{l}}{R_\mathrm{w}} + x_\mathrm{w}} \; \dfrac{p}{p_\mathrm{dsat}(p,t)} \cdot 100\%$

with $p_\mathrm{dsat}(p,t)$ for $t \geq 0.01\,°\mathrm{C}$ - Vapour pressure of water in gas mixtures

for $t < 0.01\,°\mathrm{C}$ - Sublimation pressures of water in gas mixtures

Result for incorrect input values:

$\mathrm{Phi_ptcomp_HuGas} = -1 \cdot 10^{100}$

Reference:

$p_\mathrm{dsat}(p,t)$ for $t \geq 0.01\,°\mathrm{C}$ from IAPWS-IF97 [1], [2], [3], [4]

$p_\mathrm{dsat}(p,t)$ for $t < 0.01\,°\mathrm{C}$ from IAPWS-92 [24]

Prandtl Number *Pr* = f(*p*,*t*,type,comp(1:8))

Function Name:

Pr_ptcomp_HuGas

Input values:

p - Pressure *p* in bar

t - Temperature *t* in °C

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Pr_ptcomp_HuGas - Prandtl-number

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

- *Prandtl*-number $Pr = \frac{\nu}{a} = \frac{\eta \cdot c_p}{\lambda}$
- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for liquid fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water
- for ice fog ($\psi_w > \psi_{w,sat}$, $t < 0.01$ °C) as saturated humid gas mixture

Result for incorrect input values:

$$\text{Pr_ptcomp_HuGas} = -1 \cdot 10^{100}$$

Reference:

Gas	c_p - ideal part	c_p - real part	η	λ
Ar	[26]	[27]	[33]	[33]
Ne	[26]	-	[34]	[34],[35],[40],[41]
N_2	[26]	[28]	[36]	[42]
O_2	[26]	[29]	[37]	[37]
CO	[26]	-	[38]	[38]
CO_2	[26]	[30]	[39]	[43]
H_2O	[26]	[31]	[17]	[16]
SO_2	[26]	-	[34]	[34],[35],[40]

Gas Constant *R* = f(type,comp(1:8))

Function Name:

R_comp_HuGas

Input values:

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

R_comp_HuGas - Gas constant in kJ/(kg K)

Result for incorrect input values:

$$R_comp_HuGas = -1 \cdot 10^{100}$$

Reference: [32]

Region = f(*h*,*s*,type,comp(1:8))

Function Name:

Region_hscomp_HuGas

Input values:

h - Specific enthalpy *h* in kJ/kg

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

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Region_hscomp_HuGas - State point of humid gas mixture

= 0 → Out of range of validity	= 6 → Pure liquid water
= 1 → Dry gas mixture	= 7 → Pure water-wet steam
= 2 → Unsaturated Gas mixture	= 8 → Pure steam
= 3 → Liquid fog = 4 → Ice fog	= 10 → The CO2 in the gas mixture would be partly liquid. Calculation is terminated.
= 5 → Liquid-ice fog at 0.01 °C exactly	= 11 → The SO2 in the gas mixture would be partly liquid. Calculation is terminated.

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *p* and *t* from s(p,t,comp) and h(p,t,comp) and calculation of *Region* from Region(p,t,comp)

Result for incorrect input values:

Region_hscomp_HuGas = 0

Reference:

Gas	*h*, *s* - ideal part	*h*, *s* - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Region = f(*p*,*h*,type,comp(1:8))

Function Name:

Region_phcomp_HuGas

Input values:

p - Pressure *p* in bar

h - Specific enthalpy *h* in kJ/kg

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Region_phcomp_HuGas - State point of humid gas mixture

= 0 → Out of range of validity	= 6 → Pure liquid water
= 1 → Dry gas mixture	= 7 → Pure water-wet steam
= 2 → Unsaturated Gas mixture	= 8 → Pure steam
= 3 → Liquid fog = 4 → Ice fog	= 10 → The CO2 in the gas mixture would be partly liquid. Calculation is terminated.
= 5 → Liquid-ice fog at 0.01 °C exactly	= 11 → The SO2 in the gas mixture would be partly liquid. Calculation is terminated.

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *t* from h(p,t,comp) and calculation of *Region* from Region(p,t,comp)

Result for incorrect input values:

Region_phcomp_HuGas = 0

Reference:

Gas	*h* - ideal part	*h* - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Region = f(*p*,*s*,type,comp(1:8))

Function Name:

Region_pscomp_HuGas

Input values:

p - Pressure *p* in bar

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

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Region_pscomp_HuGas - State point of humid gas mixture

= 0 → Out of range of validity	= 6 → Pure liquid water
= 1 → Dry gas mixture	= 7 → Pure water-wet steam
= 2 → Unsaturated Gas mixture	= 8 → Pure steam
= 3 → Liquid fog = 4 → Ice fog	= 10 → The CO2 in the gas mixture would be partly liquid. Calculation is terminated.
= 5 → Liquid-ice fog at 0.01 °C exactly	= 11 → The SO2 in the gas mixture would be partly liquid. Calculation is terminated.

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *t* from s(p,t,comp) and calculation of *Region* from Region(p,t,comp)

Result for incorrect input values:

Region_pscomp_HuGas = 0

Reference:

Gas	*s* - ideal part	*s* - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Region = f(*p*,*t*,type,comp(1:8))

Function Name:

Region_ptcomp_HuGas

Input values:

p - Pressure *p* in bar

t - Temperature *t* in °C

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Region_ptcomp_HuGas - State point of humid gas mixture

= 0 → Out of range of validity	= 6 → Pure liquid water
= 1 → Dry gas mixture	= 7 → Pure water-wet steam
= 2 → Unsaturated Gas mixture	= 8 → Pure steam
= 3 → Liquid fog = 4 → Ice fog	= 10 → The CO2 in the gas mixture would be partly liquid. Calculation is terminated.
= 5 → Liquid-ice fog at 0.01 °C exactly	= 11 → The SO2 in the gas mixture would be partly liquid. Calculation is terminated.

Range of validity:

Temperature *t* : - 70 °C $\leq$ *t* $\leq$ 3026.85 °C

Pressure *p*: 0.01 bar $\leq$ *p* $\leq$ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice

Result for incorrect input values:

Region_ptcomp_HuGas = 0

Region = f(*t*,*s*,type,comp(1:8))

Function Name:

Region_tscomp_HuGas

Input values:

t - Temperature *t* in °C

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

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Region_tscomp_HuGas - State point of humid gas mixture

= 0 → Out of range of validity	= 6 → Pure liquid water
= 1 → Dry gas mixture	= 7 → Pure water-wet steam
= 2 → Unsaturated Gas mixture	= 8 → Pure steam
= 3 → Liquid fog = 4 → Ice fog	= 10 → The CO2 in the gas mixture would be partly liquid. Calculation is terminated.
= 5 → Liquid-ice fog at 0.01 °C exactly	= 11 → The SO2 in the gas mixture would be partly liquid. Calculation is terminated.

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *p* from s(p,t,comp) and calculation of *Region* from Region(p,t,comp)

Result for incorrect input values:

Region_tscomp_HuGas = 0

Reference:

Gas	*s* - ideal part	*s* - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Density ρ = f(p,t,type,comp(1:8))

Function Name:

rho_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

rho_ptcomp_HuGas - Density in kg/m³

Range of validity:

Temperature t : - 70 °C $\leq$ t $\leq$ 3026.85 °C

Pressure p: 0.01 bar $\leq$ p $\leq$ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice

Result for incorrect input values:

$$\text{rho_ptcomp_HuGas} = -1 \cdot 10^{100}$$

Reference:

Gas	ρ - ideal part	ρ - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N_2	[26]	[28]	-
O_2	[26]	[29]	-
CO	[26]	-	-
CO_2	[26]	[30]	-
H_2O	[26]	[31]	[25]
SO_2	[26]	-	-

Specific Entropy *s* = f(*p*,*h*,type,comp(1:8))

Function Name:

s_phcomp_HuGas

Input values:

p - Pressure *p* in bar

h - Specific enthalpy *h* in kJ/kg

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

s_phcomp_HuGas - Specific entropy in kJ/(kg K)

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *t* from h(p,t,comp) and calculation of *s* from s(p,t,comp)

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice
- Effects of dissociation are considered for temperatures greater than 500 °C

Result for incorrect input values:

$$s_phcomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	*h*,*s* - ideal part	*h*,*s* - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N_2	[26]	[28]	-
O_2	[26]	[29]	-
CO	[26]	-	-
CO_2	[26]	[30]	-
H_2O	[26]	[31]	[25]
SO_2	[26]	-	-

Specific Entropy *s* = f(*p*,*t*,type,comp(1:8))

Function Name:

s_ptcomp_HuGas

Input values:

p - Pressure *p* in bar

t - Temperature *t* in °C

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

s_ptcomp_HuGas - Specific entropy in kJ/(kg K)

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice
- Effects of dissociation are considered for temperatures greater than 500 °C

Result for incorrect input values:

$$s_ptcomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	*s* - ideal part	*s* - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N_2	[26]	[28]	-
O_2	[26]	[29]	-
CO	[26]	-	-
CO_2	[26]	[30]	-
H_2O	[26]	[31]	[25]
SO_2	[26]	-	-

Surface Tension of Water σ_w = f(t)

Function Name:

Sigmaw_t_HuGas

Input values:

t - Temperature t in °C

Result:

Sigmaw_t_HuGas - Surface tension of water σ_w in N/m

Range of validity:

Temperature t : 0 °C $\leq$ t $\leq$ 373.946 °C

Comments:

Calculation for pure water from IAPWS-IF97

Result for incorrect input values:

$$\text{sigmaw_t_HuGas} = -1 \cdot 10^{100}$$

References: [8]

Temperature *t* = f(*h*,*s*,type,comp(1:8))

Function Name:

t_hscomp_HuGas

Input values:

h - Specific enthalpy *h* in kJ/kg

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

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

t_hscomp_HuGas - Temperature t in °C

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *p* and *t* from h(p,t,comp) and s(p,t,comp)

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$)as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice
- Effects of dissociation are considered for temperatures greater than 500 °C

Result for incorrect input values:

$$t_hscomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	*h*,*s* - ideal part	*h*,*s* - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Temperature *t* = f(*p*,*h*,type,comp(1:8))

Function Name:

t_phcomp_HuGas

Input values:

p - Pressure *p* in bar

h - Specific enthalpy *h* in kJ/kg

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

t_phcomp_HuGas - Temperature in °C

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *t* from h(p,t,comp)

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice
- Effects of dissociation are considered for temperatures greater than 500 °C

Result for incorrect input values:

$$t_phcomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	*h* - ideal part	*h* - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Temperature *t* = f(*p*,*s*,type,comp(1:8))

Function Name:

t_pscomp_HuGas

Input values:

p - Pressure *p* in bar

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

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

t_pscomp_HuGas - Temperature *t* in °C

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *t* from s(p,t,comp)

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice
- Effects of dissociation are considered for temperatures greater than 500 °C

Result for incorrect input values:

$$t_pscomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	*h*,*s* - ideal part	*h*,*s* - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Dew Point Temperature of Water $t_{w,dew}$ = f(p,type,comp(1:8))

Function Name:

twdew_pcomp_HuGas

Input values:

p - Pressure p in bar

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

twdew_pcomp_HuGas - Dew point temperature of water $t_{w,dew}$ in °C

Range of validity:

Temperature t : - 70 °C $\leq$ t $\leq$ 3026.85 °C

Pressure p: 0.01 bar $\leq$ p $\leq$ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Dew point temperature of water $t_{w,dew} = t_s(p, p_d)$ for $t \geq 0.01$ °C
(t_s – Saturation temperatureof water in gas mixtures)

$t_{w,dew} = t_{sub}(p, p_d)$ for $t < 0.01$ °C
(t_{sub} – Sublimation temperature of water in gas mixtures)

Result for incorrect input values:

$$\text{twdew_pcomp_HuGas} = -1 \cdot 10^{100}$$

References:

$t_s(p, p_d)$ for $t \geq 0.01$ °C from IAPWS-IF97 [1], [2], [3], [4]

$t_{sub}(p, p_d)$ for $t < 0.01$ °C from IAPWS-92 [24]

Internal Energy *u* = f(*p*,*t*,type,comp(1:8))

Function Name:

u_ptcomp_HuGas

Input values:

p - Pressure *p* in bar

t - Temperature *t* in °C

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

u_ptcomp_HuGas - Internal energy in kJ/kg

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice
- Effects of dissociation are considered for temperatures greater than 500 °C

Result for incorrect input values:

$$u_ptcomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	*u* - ideal part	*u* - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N_2	[26]	[28]	-
O_2	[26]	[29]	-
CO	[26]	-	-
CO_2	[26]	[30]	-
H_2O	[26]	[31]	[25]
SO_2	[26]	-	-

Specific Volume *v* = f(*h*,*s*,type,comp(1:8))

Function Name:

v_hscomp_HuGas

Input values:

h - Specific enthalpy *h* in kJ/kg

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

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

v_hscomp_HuGas - Specific volume in m³/kg

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *p* and *t* from h(p,t,comp) and s(p,t,comp) and calculation of *v* from v(p,t,comp)

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice

Result for incorrect input values:

$$v_hscomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	*v,h,s* - ideal part	*v,h,s* - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Specific Volume *v* = f(*p*,*h*,type,comp(1:8))

Function Name:

v_phcomp_HuGas

Input values:

p - Pressure *p* in bar

h - Specific enthalpy *h* in kJ/kg

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

v_phcomp_HuGas - Specific volume in m³/kg

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *t* from h(p,t,comp) and calculation of *v* from v(p,t,comp)

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice

Result for incorrect input values:

$$v_phcomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	*v,h* - ideal part	*v,h* - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Specific Volume *v* = f(*p*,*s*,type,comp(1:8))

Function Name:

v_pscomp_HuGas

Input values:

p - Pressure *p* in bar

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

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

v_pscomp_HuGas - Specific volume in m³/kg

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *t* from s(p,t,comp) and calculation of *v* from v(p,t,comp)

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice

Result for incorrect input values:

$$v_pscomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	*v,s* - ideal part	*v,s* - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Specific Volume *v* = f(*p*,*t*,type,comp(1:8))

Function Name:

v_ptcomp_HuGas

Input values:

p - Pressure *p* in bar

t - Temperature *t* in °C

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

v_ptcomp_HuGas - Specific volume in m³/kg

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice

Result for incorrect input values:

$$v_ptcomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	*v* - ideal part	*v* - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N_2	[26]	[28]	-
O_2	[26]	[29]	-
CO	[26]	-	-
CO_2	[26]	[30]	-
H_2O	[26]	[31]	[25]
SO_2	[26]	-	-

Specific Volume *v* = f(*t*,*s*,type,comp(1:8))

Function Name:

v_tscomp_HuGas

Input values:

t - Temperature *t* in °C

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

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

v_tscomp_HuGas - Specific volume in m³/kg

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *p* from s(p,t,comp) and calculation *v* from v(p,t,comp)

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real gases (dry gas and steam)
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice, calculation is not possible for liquid-ice fog at 0.01 °C

Result for incorrect input values:

$$v_tscomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	*v*,*h*,*s* ideal part	*v*,*h*,*s* real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N_2	[26]	[28]	-
O_2	[26]	[29]	-
CO	[26]	-	-
CO_2	[26]	[30]	-
H_2O	[26]	[31]	[25]
SO_2	[26]	-	-

Isentropic Speed of Sound *w* = f(*p*,*t*,type,comp(1:8))

Function Name:

w_ptcomp_HuGas

Input values:

p - Pressure *p* in bar

t - Temperature *t* in °C

type = 0 → composition as mole fraction
= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

w_ptcomp_HuGas - Isentropic speed of sound in m/s

Range of validity:

Temperature *t* : - 70 °C ≤ *t* ≤ 3026.85 °C

Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$)

$$w = \sqrt{-v^2 \cdot \left(\frac{\partial p}{\partial v}\right)_T \cdot \frac{c_p}{c_v}}$$

- for liquid fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water

- for ice fog ($\psi_w > \psi_{w,sat}$, $t < 0.01$ °C) as saturated humid gas mixture

Result for incorrect input values:

$$w_ptcomp_HuGas = -1 \cdot 10^{100}$$

Reference:

Gas	v, c_p, c_v - ideal part	v, c_p, c_v - real part
Ar	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Humidity Ratio (Absolute Humidity) x_w = f(type,comp(1:8))

Function Name:

xw_comp_HuGas

Input values:

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

xw_comp_HuGas - Humidity ratio in g_{Water}/kg_{Gas}

Comments:

Humidity ratio of water $x_w = \dfrac{\psi_w}{\dfrac{R_w}{R_{mix}} - \psi_w}$

Result for incorrect input values:

$xw_comp_HuGas = -1 \cdot 10^{100}$

Mole Fraction of Liquid Water ψ_{wl} = f(p,t,type,comp(1:8))

Function Name:

Psiwl_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Psiwl_ptcomp_HuGas - Mole fraction of water in kmol/kmol

Range of validity:

Temperature t : t_τ (p,comp) $\leq$ t $\leq$ $t_s(p,p_d)$

(t_s – Saturation temperatureof water in gas mixtures)

Pressure p: 0.01 bar $\leq$ p $\leq$ 1000 bar

Comments:

Mole fraction of liquid water: $\psi_{wl} = \psi_w - \psi_{wsat}$

with $\psi_{wsat} = \dfrac{p_{dsat}(p,t)}{p}$

with $p_{dsat}(p,t)$ for $t \geq$ 0.01 °C – Vapour pressure of water in gas mixtures

for $t <$ 0.01 °C – Sublimation pressure of water in gas mixtures

Result for incorrect input values:

$\text{Psiwl_ptcomp_HuGas} = -1 \cdot 10^{100}$

Reference:

$p_{dsat}(p,t)$ for $t \geq$ 0.01 °C from IAPWS-IF97 [1], [2], [3], [4]

$p_{dsat}(p,t)$ for $t <$ 0.01 °C from IAPWS-92 [24]

Mole Fraction of Water of Saturated Gas
$\psi_{w,sat}$ = f(p,t,type,comp(1:8))

Function Name:

Psiwsat_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

type = 0 $\rightarrow$ composition as mole fraction
= 1 $\rightarrow$ composition as mass fraction

comp - Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Psiwsat_ptcomp_HuGas – Mole fraction of water of saturated gas $\psi_{w,sat}$ in kmol/ kmol

Range of validity:

Temperature t : - 70 °C $\leq$ t $\leq$ $t_s(p, p_d)$
(t_s – Saturation temperatureof water in gas mixtures)

Pressure p: 0.01 bar $\leq$ p $\leq$ 1000 bar

Comments:

Mole fraction of liquid water: $\psi_{wsat} = \dfrac{p_{dsat}(p,t)}{p}$

with $p_{dsat}(p,t)$ for $t \geq$ 0.01 °C – Vapour pressure of water in gas mixtures
for $t <$ 0.01 °C – Sublimation pressure of water in gas mixtures

Result for incorrect input values:

$$\text{Psiwsat_ptcomp_HuGas} = -1 \cdot 10^{100}$$

Reference:

$p_{dsat}(p,t)$ for $t \geq$ 0.01 °C from IAPWS-IF97 [1], [2], [3], [4]

$p_{dsat}(p,t)$ for $t <$ 0.01 °C from IAPWS-92 [24]

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

Water and Steam

Library LibIF97

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

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:

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

and of the ideal gases:

SO_2, CO, Ne (Scientific Formulation of Bücker et al.)

Consideration of:

Dissociation from VDI 4670 and Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:

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

Consideration of:

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

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (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 Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

$C_2H_6O_2$	Ethylene glycol
$C_3H_8O_2$	Propylene glycol
C_2H_5OH	Ethyl alcohol
CH_3OH	Methyl alcohol
$C_3H_8O_3$	Glycerol
K_2CO_3	Potassium carbonate
$CaCl_2$	Calcium chloride
$MgCl_2$	Magnesium chloride
NaCl	Sodium chloride
$C_2H_3KO_2$	Potassium acetate

Formulation of the International Institute of Refrigeration (1997)

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
Library LibN2
Formulation of Span et al. (2000)

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**
Dinitrogen monooxide N_2O **Library LibN2O**
Sulfur dioxide SO_2 **Library LibSO2**
Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

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Fax.: +49-3583-61-1846

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

www.thermodynamic-property-libraries.com

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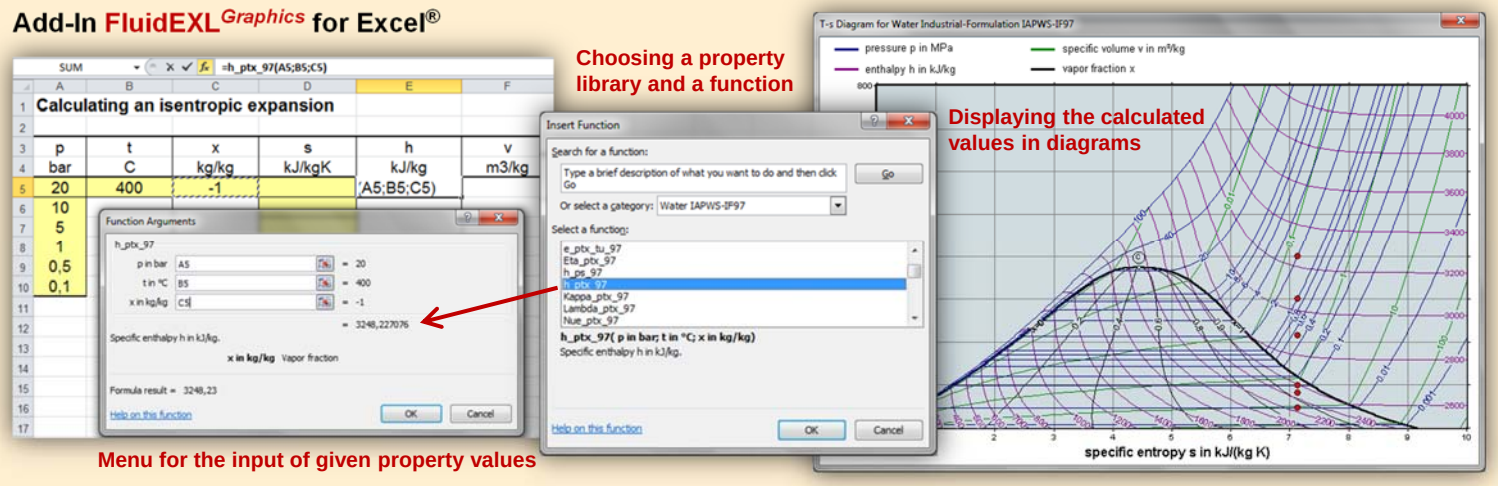
Department of Technical Thermodynamics
www.thermodynamics-zittau.de

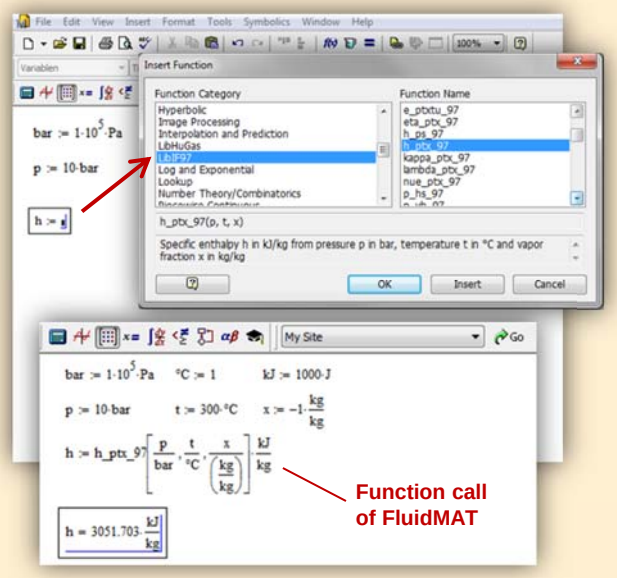
Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Add-In FluidEXL*Graphics* for Excel®



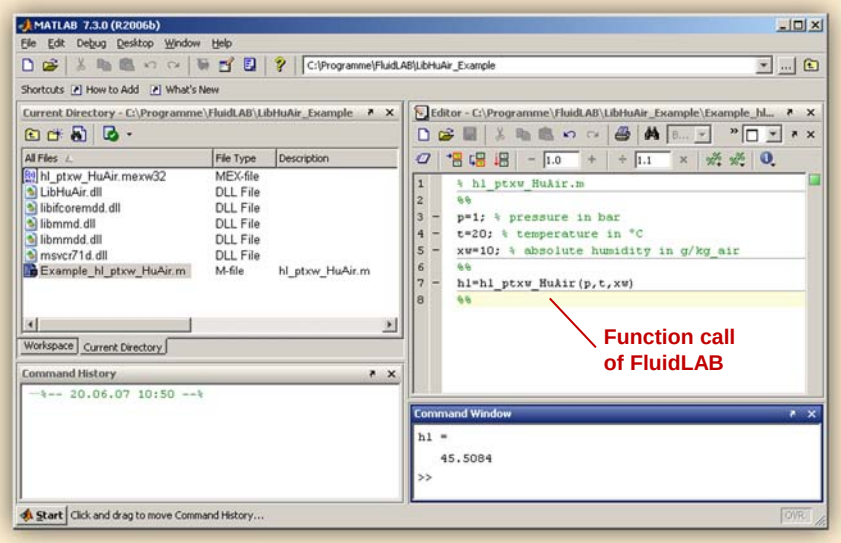
Add-In FluidMAT for Mathcad®

The property libraries can be used in Mathcad®.



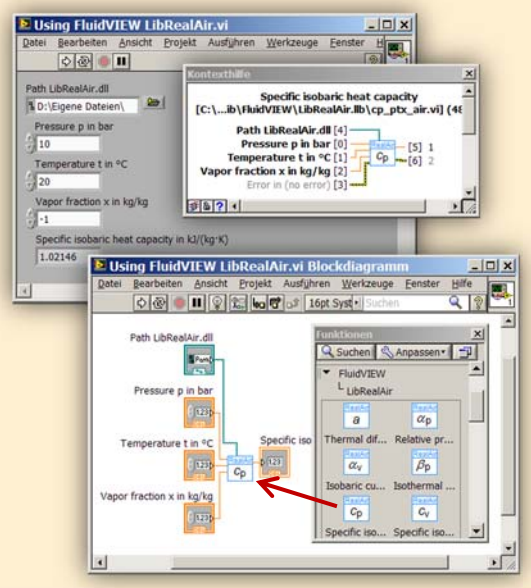
Add-In FluidLAB for MATLAB®

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



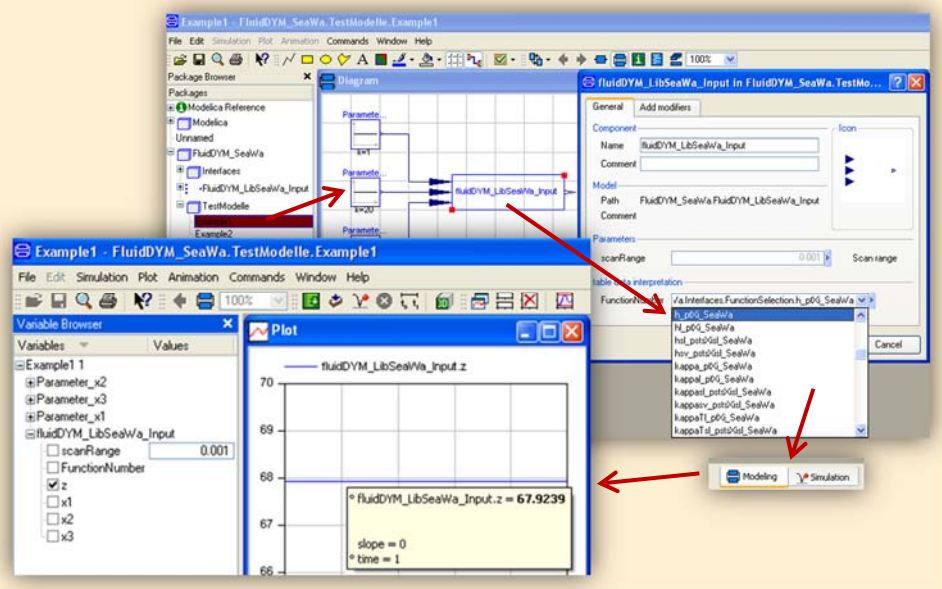
Add-On FluidVIEW for LabVIEW®

The property functions can be calculated in LabVIEW®.

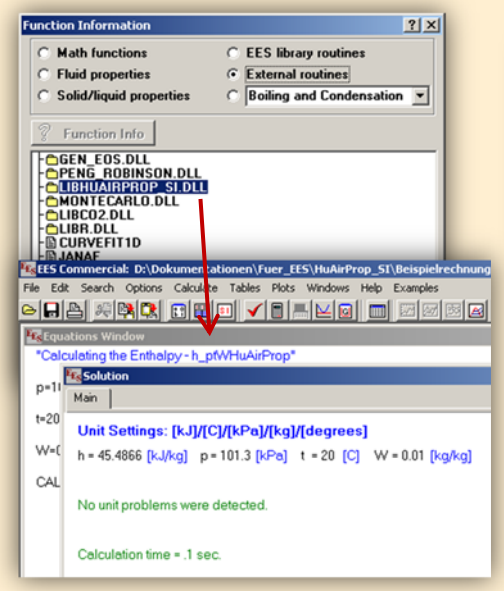


Add-In FluidDYM for DYMOLA® (Modelica) and SimulationX®

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



Add-In FluidEES for Engineering Equation Solver®



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

Online Property Calculator at www.thermodynamics-zittau.de

Property Software for Pocket Calculators

FluidCasio

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

FluidHP

HP 48 | HP 49

FluidTI

TI Nspire CX CAS
TI Nspire CAS

TI 83
TI 84
TI 89

TI Voyage 200

TI 92

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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.thermodynamic-property-libraries.com

5. References

[1] Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam IAPWS-IF97.
IAPWS Sekretariat, Dooley, B, EPRI, Palo Alto CA (1997)

[2] Wagner, W.; Kruse, A.:
Zustandsgrößen von Wasser und Wasserdampf.
Springer-Verlag, Berlin (1998)

[3] Wagner, W.; Cooper, J.R.; Dittmann, A.; Kijima, J.; Kretzschmar, H.-J.; Kruse, A.; Mares, R.; Oguchi, K.; Sato, H.; Stöcker, I.; Sifner, O.; Takaishi, Y.; Tanishita, I.; Trübenbach, J.; Willkommen, Th.:
The IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam.
ASME Journal of Eng. for Gas Turbines and Power 122 (2000) Nr. 1, S. 150-182

[4] Kretzschmar, H.-J.; Stöcker, I.; Klinger, J.; Dittmann, A.:
Calculation of Thermodynamic Derivatives for Water and Steam Using the New Industrial Formulation IAPWS-IF97.
in: Steam, Water and Hydrothermal Systems: Physics and Chemistry Meeting the Needs of Industry, Proceedings of the 13th International Conference on the Properties of Water and Steam, Eds. P.G. Hill et al., NRC Press, Ottawa, 2000

[5] Kretzschmar, H.-J.:
Mollier h,s-Diagramm.
Springer-Verlag, Berlin (1998)

[6] Revised Release on the IAPS Formulation 1985 for the Thermal Conductivity of Ordinary Water Substance.
IAPWS Sekretariat, Dooley, B., EPRI, Palo Alto CA, (1997)

[7] Revised Release on the IAPS Formulation 1985 for the Viscosity of Ordinary Water Substance.
IAPWS Secretariat, Dooley, B., EPRI, Palo Alto CA, (1997)

[8] IAPWS Release on Surface Tension of Ordinary Water Substance 1994.
IAPWS Sekretariat, Dooley, B., EPRI, Palo Alto CA, (1994)

[9] Kretzschmar, H.-J.; Stöcker, I.; Willkommen, Th.; Trübenbach, J.; Dittmann, A.:
Supplementary Equations $v(p,T)$ for the Critical Region to the New Industrial Formulation IAPWS-IF97 for Water and Steam.
in: Steam, Water and Hydrothermal Systems: Physics and Chemistry Meeting the Needs of Industry, Proceedings of the 13th International Conference on the Properties of Water and Steam, Eds. P.G. Hill et al., NRC Press, Ottawa, 2000

[10] Kretzschmar, H.-J.; Stöcker, I.; Knobloch, K.; Trübenbach, J.; Willkommen, Th.; Dittmann, A.; Friend, D.:
Supplementary Backward Equations $p(h,s)$ to the Industrial Formulation IAPWS-IF97 for Water and Steam.
ASME Journal of Engineering for Gas Turbines and Power – is under way

[11] Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use.
IAPWS Sekretariat, Dooley, B., EPRI, Palo Alto CA, (1995)

[12] Grigull, U.:
Properties of Water and Steam in SI Units.
Springer-Verlag, Berlin (1989)

[13] Kretzschmar, H.-J.:
Zur Aufbereitung und Darbietung thermophysikalischer Stoffdaten für die Energietechnik.
Habilitation, TU Dresden, Fakultät Maschinenwesen (1990)

[14] Baehr, H.D.; Diederichsen, Ch.:
Berechnungsgleichungen für Enthalpie und Entropie der Komponenten von Luft und Verbrennungsgasen.
BWK 40 (1988) Nr. 1/2, S. 30-33

[15] Brandt, F.:
Wärmeübertragung in Dampferzeugern und Wärmetauschern.
FDBR-Fachbuchreihe, Bd. 2, Vulkan Verlag Essen (1985)

[16] Release on the IAPS Formulation 1985 for the Thermal Conductivity of Ordinary Water Substance.
IAPWS Sekretariat, Dooley, B., EPRI, Palo Alto CA, (1985)

[17] Release on the IAPS Formulation 1985 for the Viscosity of Ordinary Water Substance.
IAPWS Secretariat, Dooley, B., EPRI, Palo Alto CA, (1985)

[18] Release on Surface Tension of Ordinary Water Substance 1975.
IAPWS Sekretariat, Dooley, B., EPRI, Palo Alto CA, (1975)

[19] VDI-Wärmeatlas, 7. Auflage.
VDI-Verlag, Düsseldorf (1995)

[20] Blanke, W.:
Thermophysikalische Stoffgrößen.
Springer-Verlag, Berlin (1989)

[21] VDI-Richtlinie 4670
Thermodynamische Stoffwerte von feuchter Luft und Verbrennungsgasen.
VDI-Handbuch Energietechnik, VDI-Gesellschaft Energietechnik, Düsseldorf (2000)

[22] Lemmon, E. W.; Jacobsen, R. T.; Penoncello, S. G.; Friend, D. G.:
Thermodynamic Properties of Air and Mixtures of Nitrogen, Argon and Oxygen from 60 to 2000 K at Pressures to 2000 MPa.
J. Phys. Chem. Ref. Data 29 (2000) Nr. 2, S. 331-385

[23] Lemmon, E. W.; Jacobsen, R. T:
Transport Properties of Air.
National Institute of Standards and Technology, Boulder CO, (2000),
private communication

[24] Revised Release on Pressure along the Melting and Sublimation Curves of Ordinary Water Substance.
IAPWS Sekretariat, Dooley, B., EPRI, Palo Alto CA (1993)

[25] Hyland, R. W.; Wexler, A.:
Formulations for the Thermodynamic Properties of Saturated Phases of H_2O from 173.15 K to 473.15 K.
Report No. 2793 (RP-216), National Bureau of Standards, Washington, D.C. (1983)

[26] Bücker, D.; Span, R.; Wagner, W.:
Thermodynamic Property Models for Moist Air and Combustion Gases.
J. Eng. Gas Turb. Power 125 (2003) 374-383.

[27] Tegeler, Ch.; Span, R.; Wagner, W.:
A New Equation of State for Argon Covering the Fluid Region for Temperatures From the Melting Line to 700 K at Pressure up to 1000 MPa.
J. Phys. Chem. Ref. Data 28 (1999) 779-850.

[28] Span, R.; Lemmon, E. W.; Jacobsen, R. T.; Wagner, W.; Yokozeki, A.:
A Reference Equation of State for the Thermodynamic Properties of Nitrogen for Temperatures from 63.151 to 1000 K and Pressures to 2200 MPa.
J. Phys. Chem. Ref. Data 29 (2000) 1361-1433.

[29] de Reuck, K. M.; Wagner, W.:
Oxygen - International Thermodynamic Tables of the Fluid State – 9.
IUPAC Thermodynamic Tables Project, Blackwell Scientific Publications, Oxford, UK, 1987.

[30] Span, R.; Wagner, W.:
A New Equation of State for Carbon Dioxide Covering the Fluid Region from the Triple-Point Temperature to 1100 K at Pressures up to 800 MPa.
J. Phys. Chem. Ref. Data 25 (1996) 1509-1596.

[31] Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use.
The Internal Association for the Properties of Water and Steam, Fredericia (1996)

[32] Verein Deutscher Ingenieure
Thermodynamische Stoffwerte von feuchter Luft und Verbrennungsgasen.
VDI 4670, Entwurf (2000)

[33] Lemmon, E. W.; Jacobsen, R. T.:
Preliminary equation for viscosity and thermal conductivity of argon.
NIST (2001)

[34] Klein, S. A.; Mc Linden, M. O.; Laesecke, A.:
An improved extended corresponding states method for estimation of viscosity of pure refrigerants and mixtures.
International Journal of Refrigeration 20 (1997) p. 208-217

[35] McLinden, M. O.; Klein, S. A.; and Perkins, R. A.:
An extended corresponding states model for the thermal conductivity of refrigerants and refrigerant mixtures.
Int. J. Refrigeration, 23 (2000) p. 43-63

[36] Lemmon, E. W.; Jacobsen, R. T.:
Preliminary equation for viscosity of nitrogen.
NIST (1999)

[37] Lemmon, E. W.; Jacobsen, R. T.:
Preliminary equation for viscosity and thermal conductivity of oxygen.
NIST (2001)

[38] National Institute of Standards and Technology
Viscosity and thermal conductivity of carbon monoxide.
Coefficients are taken from NIST14, Version 9.08

[39] Fenghour, A.; Wakeham, W. A.; Vesovic, V.:
The viscosity of carbon dioxide.
Journal of Physical and Chemical Reference Data 27 (1998) No. 1

[40] Reid, R. C.; Prausnitz, J. M.; Poling, B. E.:
The Properties of Gases and Liquids.
4th edition, McGraw-Hill Book Company, New York (1987)

[41] Rabinovich, V. A.; Vasserman, A. A.; Nedostup, V. I.; Veksler, L. S.:
Thermophysical Properties of Neon, Argon, Krypton, and Xenon.
Hemisphere Publishing Corp., New York (1988)

[42] Lemmon, E. W.; Jacobsen, R. T.:
Preliminary equation for thermal conductivity of nitrogen.
NIST (1999)

[43] Vesovic, V.; Wakeham, W. A.; Olchowy, G. A.; Sengers, J. V.; Watson, J. T. R.; Millat, J.:
The transport properties of carbon dioxide.
J. Phys. Chem. Ref. Data, 19 (1990) p. 763-808

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®:

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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
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KIT-TVT, Karlsruhe	02/2014
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Siemens, Muehlheim	11/2012
Sennheiser, Hannover	11/2012
Oschatz GmbH, Essen	10/2012
Fichtner IT, Stuttgart	10/2012, 11/2012
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Fichtner IT Consult, Chennai, India	06/2012
Siemens, Freiburg	06/2012
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Niederrhein University of Applied Sciences, Krefeld	06/2012
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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
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Concordia University, Montreal, Canada	09/2010
Compañía Eléctrica de Sochagota, Bogota, Colombia	08/2010
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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
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University of Glasgow, Great Britain	04/2010
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HUBER Consulting Engineers, Berching	04/2010
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Offenburg University of Applied Sciences	03/2010
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NIST Boulder CO, USA	03/2010
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Siemens Energy, Nuremberg	02/2010
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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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Technical University of Freiberg	01/2010
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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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Brandenburg University of Technology, Cottbus	02/2009
Hamburg University of Applied Sciences	02/2009
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Bernd Münstermann, Telgte	03/2009
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CPP, Marburg	03/2009
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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
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Nuernberg University of Applied Sciences	06/2009
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Fraunhofer Institut UMSICHT, Oberhausen	07/2009
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Techsoft, Linz, Austria	08/2009
DLR, Stuttgart	08/2009
Wienstrom, Vienna, Austria	08/2009
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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
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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
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ThyssenKrupp Marine Systems, Kiel	07/2006
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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
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KEMA IEV, Dresden	12/2005

2004

Vattenfall Europe (group license)	01/2004
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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
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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InfraServ, Gendorf	05/2002
SoftSolutions, Muehlhausen (company license)	05/2002
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Fichtner Consulting & IT, Stuttgart (company licenses and distribution)	08/2002
Stadtwerke Duisburg	08/2002
Stadtwerke Hannover	09/2002
Siemens Power Generation, Goerlitz	10/2002
Energieversorgung Halle (company license)	10/2002
Bayer, Leverkusen	11/2002
Dillinger Huette, Dillingen	11/2002
G.U.N.T. Geraetebau, Barsbuettel (general license and training test benches)	12/2002
VEAG, Berlin (group license)	12/2002

2001

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

Siemens, Karlsruhe (general license for the WinIS information system)	08/2001
Neusiedler AG, Ulmerfeld, Austria	09/2001
h s energieanlagen, Freising	09/2001
Electrowatt-EKONO, Zurich, Switzerland	09/2001
IPM Zittau/Goerlitz University of Applied Sciences (general license)	10/2001
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AG KKK - PGW Turbo, Leipzig	01/2000
PREUSSAG NOELL, Wuerzburg	01/2000
M&M Turbine Technology, Bielefeld	01/2000
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GK, Hannover	03/2000
KRUPP-UHDE, Dortmund (company license)	03/2000
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Thinius Engineering, Erkrath	04/2000
SaarEnergie, Saarbruecken	05/2000, 08/2000
DVO Data Processing Service, Oberhausen	05/2000
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VAUP Process Automation, Landau	08/2000
Knuerr-Lommatec, Lommatzsch	09/2000
AVACON, Helmstedt	10/2000
Compania Electrica, Bogota, Colombia	10/2000
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Bayernwerk, Munich	01/1999
DREWAG, Dresden (company license)	02/1999
KEMA IEV, Dresden	03/1999

Regensburg University of Applied Sciences	04/1999
Fichtner Consulting & IT, Stuttgart (company licenses and distribution)	07/1999
Technical University of Cottbus, Chair in Power Plant Engineering	07/1999
Technical University of Graz, Department of Thermal Engineering, Austria	11/1999
Ostendorf Engineering, Gummersbach	12/1999

1998

Technical University of Cottbus, Chair in Power Plant Engineering	05/1998
Fichtner Consulting & IT (CADIS information systems) Stuttgart (general KPRO program license)	05/1998
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B+H Software Engineering Stuttgart	08/1998
Alfa Engineering, Switzerland	09/1998
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SCA Hygiene Products, Munich	10/1998
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1997

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