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Property Library for Humid Gas Mixtures

FluidMAT
with **LibHuGas**
for Mathcad®

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Software for the Calculation of the Properties of Humid Gas Mixtures

LibHuGas FluidMAT for Mathcad®

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0 Package Contents

English zip file "CD_FluidMAT_LibHuGas_Eng.zip" includes the following files:

FluidMAT_LibHuGas_Setup.exe	- Self-extracting and self-installing program
LibHuGas.dll	- DLL with functions of the LibHuGas library
FluidMAT_LibHuGas_Docu_Eng.pdf	- User's Guide

German zip file "CD_FluidMAT_LibHuGas.zip" includes the following files:

FluidMAT_LibHuGas_Setup.exe	- Self-extracting and self-installing program
LibHuGas.dll	- DLL with functions of the LibHuGas library
FluidMAT_LibHuGas_Docu_Eng.pdf	- User's Guide

1. Property Functions

Function	Function Name	Call of Fortran Program	Property or Function	Unit
$a = f(p, t)$	a_ptcomp_HuGas	= a_pTcomp_HuGas(p, T, type, comp)	Thermal diffusivity	m^2/s
$c_p = f(h, s)$	cp_hscomp_HuGas	= cp_hscomp_HuGas(h, s, type, comp)	Backward function: Specific isobaric heat capacity from enthalpy and entropy	$\text{kJ}/(\text{kg} \cdot \text{K})$
$c_p = f(p, h)$	cp_phcomp_HuGas	= cp_phcomp_HuGas(p, h, type, comp)	Backward function: Specific isobaric heat capacity from pressure and enthalpy	$\text{kJ}/(\text{kg} \cdot \text{K})$
$c_p = f(p, s)$	cp_pscomp_HuGas	= cp_pscomp_HuGas(p, s, type, comp)	Backward function: Specific isobaric heat capacity from pressure and entropy	$\text{kJ}/(\text{kg} \cdot \text{K})$
$c_p = f(p, t)$	cp_ptcomp_HuGas	= cp_pTcomp_HuGas(p, T, type, comp)	Specific isobaric heat capacity	$\text{kJ}/(\text{kg} \cdot \text{K})$
$c_p = f(t, s)$	cp_tscomp_HuGas	= cp_Tscomp_HuGas(T, s, type, comp)	Backward function: Specific isobaric heat capacity from temperature and entropy	$\text{kJ}/(\text{kg} \cdot \text{K})$
$c_v = f(p, t)$	cv_ptcomp_HuGas	= cv_pTcomp_HuGas(p, T, type, comp)	Specific isochoric heat capacity	$\text{kJ}/(\text{kg} \cdot \text{K})$
$\eta = f(p, t)$	Eta_ptcomp_HuGas	= eta_pTcomp_HuGas(p, T, type, comp)	Dynamic viscosity	$\text{Pa} \cdot \text{s}$
$h = f(p, s)$	h_pscomp_HuGas	= h_pscomp_HuGas(p, s, type, comp)	Backward function: Specific enthalpy from pressure and entropy	kJ/kg
$h = f(p, t)$	h_ptcomp_HuGas	= h_pTcomp_HuGas(p, T, type, comp)	Specific Enthalpy	kJ/kg
$h = f(t, s)$	h_tscomp_HuGas	= h_Tscomp_HuGas(T, s, type, comp)	Backward function: Specific enthalpy from temperature and entropy	kJ/kg
$\kappa = f(p, s)$	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
$\kappa = f(p, t)$	Kappa_ptcomp_HuGas	= kappa_pTcomp_HuGas(p, T, type, comp)	Isentropic exponent	-
$\lambda = f(p, t)$	Lambda_ptcomp_HuGas	= lambda_pTcomp_HuGas(p, T, type, comp)	Thermal conductivity	W/(m · K)
M	M_comp_HuGas	= M_comp_HuGas(type, comp)	Molar mass	kg/kmol
$\nu = f(p, t)$	Ny_ptcomp_HuGas	= ny_pTcomp_HuGas(p, T, type, comp)	Kinematic viscosity	m ² /s
$p = f(h, s)$	p_hscomp_HuGas	= p_hscomp_HuGas(h, s, type, comp)	Backward function: Pressure from enthalpy and entropy	bar
$p = f(t, s)$	p_tscomp_HuGas	= p_Tscomp_HuGas(T, s, type, comp)	Backward function: Pressure from temperature and entropy	bar
$p_{\text{dsat}} = f(p, t)$	pdsat_pt_HuGas	= pdsat_pT_HuGas(p, T)	Saturation pressure of water in mixture	bar
$\varphi = f(p, t)$	Phi_ptcomp_HuGas	= phi_pTcomp_HuGas(p, T, type, comp)	Relative humidity	%
$Pr = f(p, t)$	Pr_ptcomp_HuGas	= Pr_pTcomp_HuGas(p, T, type, comp)	Prandtl number	-
$\psi_{\text{wl}} = f(p, t)$	Psiwl_ptcomp_HuGas	= psiwl_pTcomp_HuGas(p, T, type, comp)	Mole fraction of water (liquid)	kmol/kmol
$\psi_{\text{wsat}} = f(p, t)$	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	kJ/(kg · K)
$Region = f(h, s)$	Region_hscomp_HuGas	= Region_hscomp_HuGas(h, s, type, comp)	Region from given enthalpy and entropy	-
$Region = f(p, h)$	Region_phcomp_HuGas	= Region_phcomp_HuGas(p, h, type, comp)	Region from given pressure and enthalpy	-
$Region = f(p, s)$	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	-
$\rho = f(p, t)$	Rho_ptcomp_HuGas	= rho_pTcomp_HuGas(p, T, type, comp)	Density	kg/m ³
$s = f(p, h)$	s_phcomp_HuGas	= s_phcomp_HuGas(p, h, type, comp)	Backward function: Specific entropy from pressure and specific enthalpy	kJ/(kg · K)
$s = f(p, t)$	s_ptcomp_HuGas	= s_pTcomp_HuGas(p, T, type, comp)	Entropy	kJ/(kg · K)
$\sigma_w = f(t)$	Sigmaw_t_HuGas	= sigmaw_T_HuGas(T)	Surface tension of water	N/m
$t = f(h, s)$	t_hscomp_HuGas	= T_hscomp_HuGas(h, s, type, comp)	Backward function: Temperature from enthalpy and entropy	°C
$t = f(p, h)$	t_phcomp_HuGas	= T_phcomp_HuGas(p, h, type, comp)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p, s)$	t_pscomp_HuGas	= T_pscomp_HuGas(p, s, type, comp)	Backward function: Temperature from pressure and entropy	°C
$t_{w,dew} = f(p)$	twdew_pcomp_HuGas	= Twdew_pcomp_HuGas(p, type, comp)	Dew point temperature of water	°C
$u = f(p, t)$	u_ptcomp_HuGas	= u_pTcomp_HuGas(p, T, type, comp)	Specific internal energy	kJ/kg
$v = f(h, s)$	v_hscomp_HuGas	= v_hscomp_HuGas(h, s, type, comp)	Backward function: Specific volume from enthalpy and entropy	m ³ /kg

Function	Function Name	Call of Fortran Program	Property or Function	Unit
$v = f(p, h)$	v_phcomp_HuGas	= v_phcomp_HuGas(p, h, type, comp)	Backward function: Specific volume from pressure and enthalpy	m ³ /kg
$v = f(p, s)$	v_pscomp_HuGas	= v_pscomp_HuGas(p, s, type, comp)	Backward function: Specific volume from pressure and entropy	m ³ /kg
$v = f(p, t)$	v_ptcomp_HuGas	= v_pTcomp_HuGas(p, T, type, comp)	Specific volume	m ³ /kg
$v = f(t, s)$	v_tscomp_HuGas	= v_Tscomp_HuGas(T, s, type, comp)	Backward function: Specific volume from temperature and entropy	m ³ /kg
$w = f(p, t)$	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 composition in mole fractions
 $type = 1$ for composition 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: $t = -70\text{ °C} \dots 3026.15\text{ °C}$

Pressure of mixture: $p = 0.01\text{ bar} \dots 1000\text{ bar}$

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 ₂ O	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 CO ₂ in the gas mixture would be partly liquid. Calculation is terminated.
11	The SO ₂ 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

$$h = h_{\text{HuGas}} - \xi_{\text{H}_2\text{O}} \cdot 2500.914579 \text{ kJ/kg}$$

$$u = u_{\text{HuGas}} - \xi_{\text{H}_2\text{O}} \cdot 2500.914579 \text{ kJ/kg}$$

$$s = s_{\text{HuGas}} - \xi_{\text{H}_2\text{O}} \cdot 9.155493408 \text{ (kJ/kg K)}$$

Conversion to the Reference States of the Publications

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

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 FluidMAT in Mathcad®

FluidMAT has been developed to calculate thermodynamic properties in Mathcad® more conveniently. Within Mathcad, it enables the direct call of functions relating to humid gas mixtures from the LibHuGas property library.

2.1 Installing FluidMAT LibHuGas

In this section, the installation of FluidMAT LibHuGas is described.

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

After you have downloaded and extracted the zip-file

"CD_FluidMAT_LibHuGas_Eng.zip" (for English version of Windows),

"CD_FluidMAT_LibHuGas.zip" (for German version of Windows),

you will see the folder

CD_FluidMAT_LibHuGas_Eng (for English version of Windows)

CD_FluidMAT_LibHuGas (for German version of Windows)

in your Windows Explorer, Norton Commander etc.

Now, open this folder by double-clicking on it.

Within this folder you will see the following files:

FluidMAT_LibHuGas_Docu_Eng.pdf

FluidMAT_LibHuGas_Setup.exe

LibHuGas.dll.

In order to run the installation of FluidMAT including the LibHuGas property library double-click the file

FluidMAT_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.

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

In the following dialog box, "Choose Destination Location" (see following figure), the default path where Mathcad has been installed will be shown

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

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

By clicking the "Browse..." button, you can change the installation directory before installation.

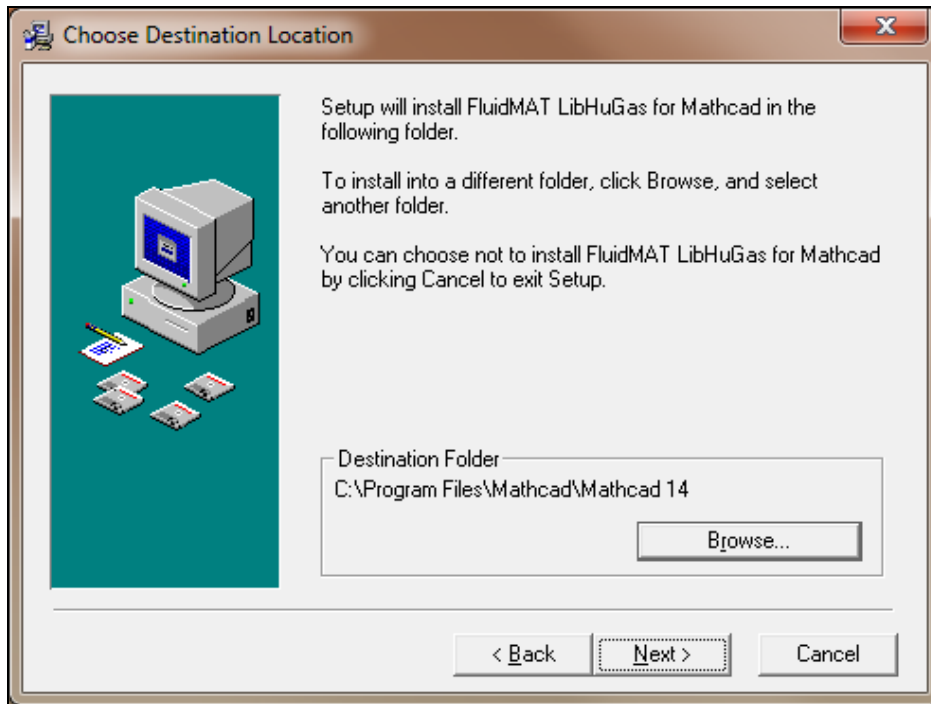


Figure 2.1: "Choose Destination Location" dialog window

The path will be displayed in the window.

Click on "Next >" in the window "Choose Destination Location".

Click on the "Next >" button in the "Start Installation" window.

After FluidMAT LibHuGas has been installed, the sentence "FluidMAT LibHuGas for Mathcad Professional has been successfully installed" will be shown.

Confirm this by clicking the "Finish >" button.

During the installation process the following files have been copied into the chosen destination folder (which is the folder, where Mathcad was installed):

advapi32.dll	Dynamic link library for use in Windows [®] programs
Dforrt.dll	Dynamic link library for use in Windows programs
Dformd.dll	Dynamic link library for use in Windows programs
LC.dll	Dynamic link library for use in Windows programs
LibHuGas.dll	Property library for ideal gases and gas mixtures
msvcpr60.dll	Dynamic link library for use in Windows programs
Msvcr7.dll	Dynamic link library for use in Windows programs
Readme.txt	ReadMe file
INSTALL_MAT_LibHuGas.LOG	Installation log-file

The following files were installed into your Mathcad subdirectory \userEFI:

MAT_LibHuGas.dll	Function definition of LibHuGas
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The following files were installed into your Mathcad subdirectory \doc\funcdoc:

MAT_LibHuGas_DE.xml	Function registration in the dialog window "Insert Function" for LibHuGas (German Mathcad version 12 or higher)
MAT_LibHuGas_EN.xml	Function registration in the dialog window "Insert Function" for LibHuGas (English Mathcad version 12 or higher)
MAT_LibHuGas.xml	Function registration in the dialog window "Insert Function" for LibHuGas (Mathcad version 11 or lower)

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

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 Mathcad directory (the standard being

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

C:\Programme\Mathcad\Mathcad 14 (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.

You have overwritten the file "LibHuGas.dll" successfully.

From within Mathcad you can now select the FluidMAT LibHuGas property functions.

2.2 Licensing the LibHuGas Property Library

The licensing procedure has to be carried out when you are calculating a function with LibHuGas in Mathcad® and a FluidMAT prompt message appears. In this case, you will see the "License Information" window for LibHuGas (see Figure 2.2).

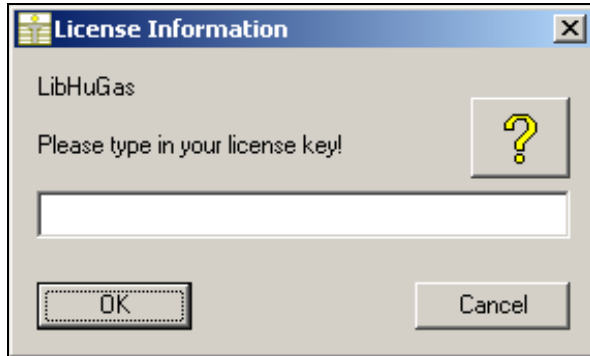


Figure 2.2: "License Information" window

Here you will have to type in the license key which you have obtained from the Zittau/Goerlitz University of Applied Sciences. You can find contact information on the "Content" page of this User's Guide or by clicking the yellow question mark in the "License Information" window. Then the following window will appear:

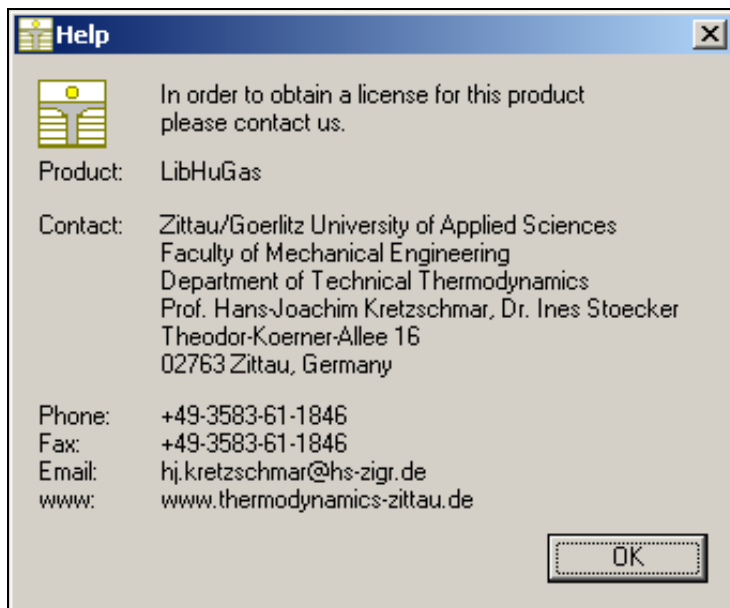


Figure 2.3: "Help" window

If you do not enter a valid license it is still possible to use Mathcad 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 the LibHuGas property library in Mathcad unless you uninstall FluidMAT.

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

2.3 Example: Calculation of $h = f(p, t, \text{type}, \text{comp}(1:8))$

Now we will calculate, step by step, the specific enthalpy h as a function of pressure, temperature, type (composition as mole or mass fractions) and composition vector of a humid gas mixture, by using FluidMAT.

Please carry out the following steps:

- Start Mathcad.
- Type "p:" and enter the value for pressure p in bar
(Range of validity of LibHuGas: $p = 0.01 \text{ bar} \dots 1000 \text{ bar}$)
⇒ e.g.: Enter "p:10"
- Type "t:" and enter the value for temperature t in °C
(Range of validity of LibHuGas: $t = -70 \text{ °C} \dots 3026.15 \text{ °C}$)
⇒ e.g.: Enter "t:500"
- Enter the value for type
(Definition of type: 0 – composition as mole fractions
1 – composition as mass fractions)
⇒ e.g.: Enter "type:0"
- Enter the composition vector as a Mathcad matrix with 8 values (in 8 rows and 1 column).
Assign this matrix to the comp variable. You have to enter "comp:" and then the matrix with the following given components:

ψ_1 for Argon	Ar	⇒ e.g.: Enter 0.0088 as 1 st value
ψ_2 for Neon	Ne	⇒ e.g.: Enter 0 as 2 nd value
ψ_3 for Nitrogen	N2	⇒ e.g.: Enter 0.7480 as 3 rd value
ψ_4 for Oxygen	O2	⇒ e.g.: Enter 0.1352 as 4 th value
ψ_5 for Carbon monoxide	CO	⇒ e.g.: Enter 0 as 5 th value
ψ_6 for Carbon dioxide	CO2	⇒ e.g.: Enter 0.0330 as 6 th value
ψ_7 for Water	H2O	⇒ e.g.: Enter 0.0750 as 7 th value
ψ_8 for Sulfur dioxide	SO2	⇒ e.g.: Enter 0 as 8 th value

The Mathcad sheet should now look as shown in Figure 2.4.

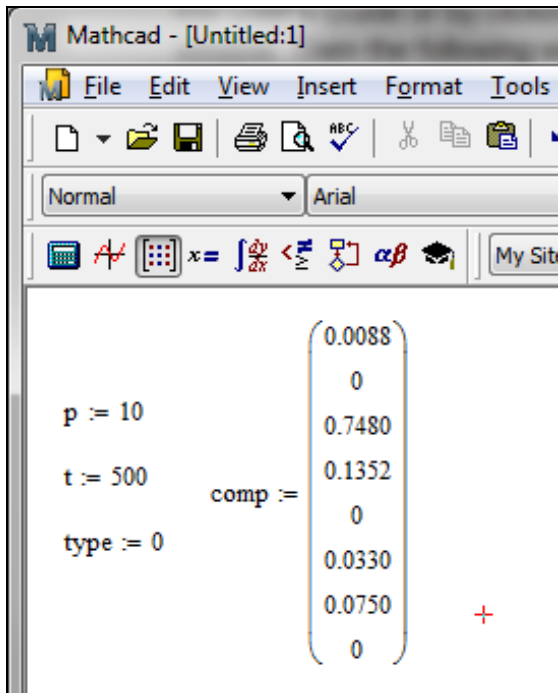


Figure 2.4: Example sheet after input of the given parameters

- Enter the symbol for the result and then a colon
⇒ e.g.: Type "h:"
- Click "Insert" in the Mathcad menu bar and then "Function..."
The "Insert Function" window appears (see Figure 2.5)
- Click "LibHuGas" under "Function Category:" on the left hand side
(see Figure 2.5)
- Click "h_ptcomp_HuGas" under "Function Name:" on the right hand side

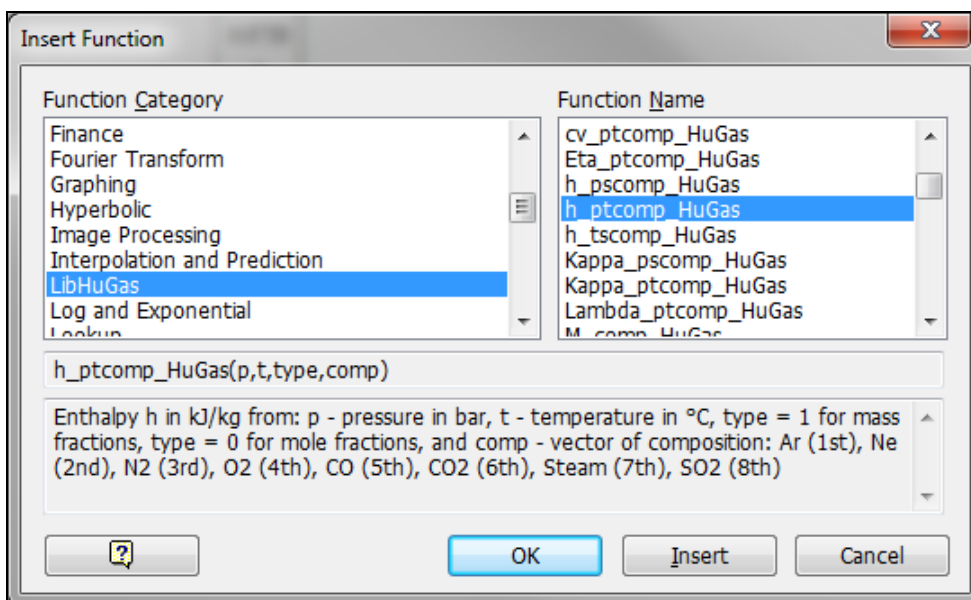


Figure 2.5: Choice of library and function name

- Click the "OK" button
Now you will see the line "**h_ptcomp_HuGas(■, ■, ■, ■)**" in the Mathcad window
(see Figure 2.6).

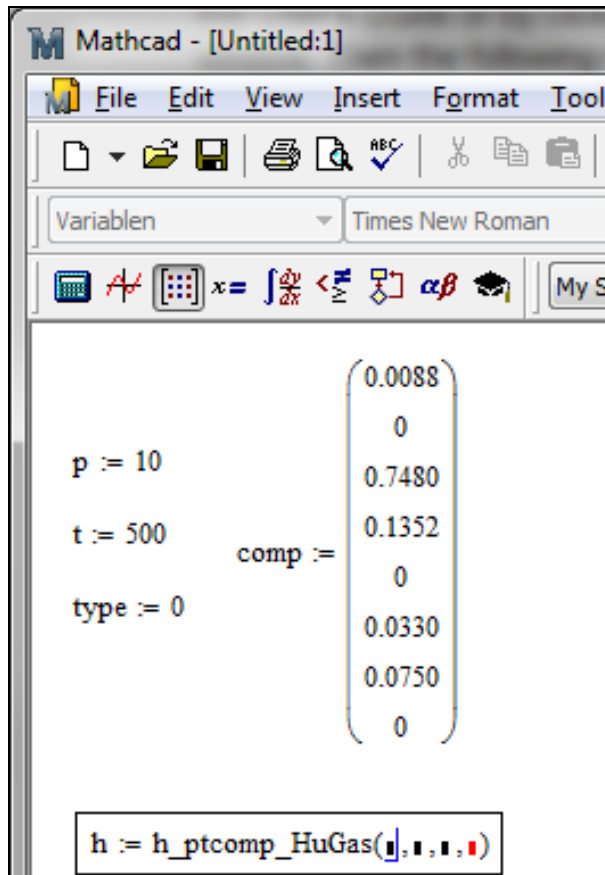


Figure 2.6: Example Mathcad sheet with formula and placeholders

- The cursor is now situated on the first operand. You can now enter the value for p either by entering the value directly or by entering the name of the variable where the value was saved.
- Place the cursor on the next placeholder. You can now enter the value for the temperature t either by entering the value for t directly or by typing the name of the variable in which the value of the temperature has been saved.

⇒ e.g.: Enter "t".

- Place the cursor on the next placeholder. You can now enter the value for the mole or mass fractions by entering the value for type directly or by entering the variable, in which this value has been saved.

If type = 0 then the input is given in mole fractions. If type = 1 then the input is given in mass fractions.

⇒ e.g.: Enter "type".

- You can now enter the composition vector comp(1:8) in the last placeholder by entering the Mathcad matrix directly or by using a variable, in which the matrix has been saved.

⇒ e.g.: Enter "comp", the name of the variable in which the composition vector is saved.

- Close the input formula by pressing the "Enter"-Key.
- Now, you can go on working with the calculated value. e.g.: You can print out the calculated value. To do this, enter " $h =$ " in the Mathcad sheet.

The result for h in kJ/kg appears (see Figure 2.7).

⇒ The result in our sample calculation here is: $h = 662.80391$ kJ/kg.

The representation of the result depends on the adjusted number decimal places.

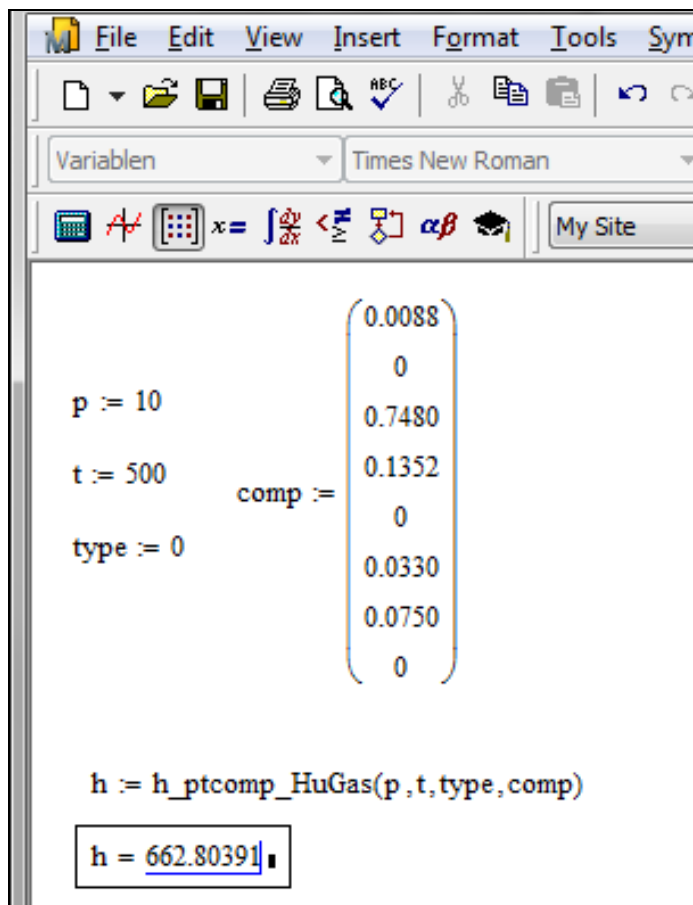


Figure 2.7: Example Mathcad sheet with finished calculation

The calculation of $h = f(p, t, type, comp(1:8))$ has been carried out.

You can now arbitrarily change the values for p , t , $type$ or $comp(1:8)$. The specific enthalpy is recalculated and updated every time you change the data. This shows that the Mathcad[®] data flow and the DLL calculations are working together successfully.

2.4 Removing FluidMAT LibHuGas

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

- Click "Start" in the lower task bar of your desktop, then "Settings" and then "Control Panel".
- Now, double click on "Add or Remove Programs".
- In the list box of the "Add or Remove Programs" window that appears select "FluidMAT LibHuGas for Mathcad Professional" by clicking on it and click the "Add/Remove..." button.
- In the following dialog box click "Automatic" and thereafter "Next >".
- Click "Finish" in the "Perform Uninstall" window.
- Finally, close the "Add or Remove Programs" and "Control Panel" windows.

Now FluidMAT has been removed.

3. Program Documentation

Thermal Diffusivity $a = f(p, t, \text{type}, \text{comp}(1:8))$

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, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

a_ptcomp_HuGas - Thermal diffusivity in m²/s

Range of validity:

Temperature t : - 70 °C ≤ t ≤ 3026.85 °C
 Pressure p : 0.01 bar ≤ p ≤ 1000 bar
 Partial pressures of CO₂ and SO₂ 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 ($\psi_w \leq \psi_{w,\text{sat}}$)

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 ₂ O	[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
 $type = 1 \rightarrow$ composition as mass fraction
 $comp$ - vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

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

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ 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:

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 ₂ O	[26]	[31]
SO ₂	[26]	-

Specific Isobaric Heat Capacity $c_p = f(p, h, \text{type}, \text{comp}(1:8))$
Function Name:

cp_phcomp_HuGas

Input values:

p - Pressure p in bar
 h - Specific enthalpy h in kJ/kg
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

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

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Iteration of t from $h(p, t, \text{comp})$ and calculation of c_p from $c_p(p, t, \text{comp})$

Calculation:

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

Result for incorrect input values:

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 ₂ O	[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
 $type = 1 \rightarrow$ composition as mass fraction
 $comp$ - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

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

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ 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:

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 ₂ O	[26]	[31]
SO ₂	[26]	-

Specific Isobaric Heat Capacity $c_p = f(p, t, \text{type}, \text{comp}(1:8))$
Function Name:

cp_ptcomp_HuGas

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

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 CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values:

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 ₂ O	[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
 $type = 1 \rightarrow$ composition as mass fraction
 $comp$ - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

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

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ 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: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 ₂ O	[26]	[31]
SO ₂	[26]	-

Specific Isochoric Heat Capacity $c_v = f(p, t, \text{type}, \text{comp}(1:8))$
Function Name:

cv_ptcomp_HuGas

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

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

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:
 - Valid only for unsaturated humid gas ($\psi_w \leq \psi_{w,\text{sat}}$)
 - 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 ₂ O	[26]	[31]
SO ₂	[26]	-

Dynamic Viscosity $\eta = f(p, t, \text{type}, \text{comp}(1:8))$
Function Name:

Eta_ptcomp_HuGas

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

Eta_ptcomp_HuGas - Dynamic viscosity in Pa s

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values: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 ₂ O	[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)
 $type = 0 \rightarrow$ composition as mole fraction
 $type = 1 \rightarrow$ composition as mass fraction
 $comp$ - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

h_pscomp_HuGas - specific enthalpy in kJ/kg

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ 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 ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Specific Enthalpy $h = f(p, t, \text{type}, \text{comp}(1:8))$
Function Name:

h_ptcomp_HuGas

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

h_ptcomp_HuGas - Specific enthalpy in kJ/kg

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 CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,\text{sat}}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,\text{sat}}$) 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 ₂ O	[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)
 $type = 0 \rightarrow$ composition as mole fraction
 $type = 1 \rightarrow$ composition as mass fraction
 $comp$ - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

`h_tscomp_HuGas` - Specific enthalpy in kJ/kg

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ 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 ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Isentropic Exponent $\kappa = f(p, t, \text{type}, \text{comp}(1:8))$
Function Name:

Kappa_ptcomp_HuGas

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

Kappa_ptcomp_HuGas - Isentropic exponent

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

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

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

- for liquid fog ($\psi_w > \psi_{w,\text{sat}}$) as ideal mixture of saturated humid gas and liquid water- for ice fog ($\psi_w > \psi_{w,\text{sat}}$, $t < 0.01\text{ °C}$) as saturated humid gas mixture**Result for incorrect input values:**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 ₂ O	[26]	[31]
SO ₂	[26]	-

Isentropic Exponent $\kappa = f(p,s,type,comp(1:8))$
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, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

Kappa_pscomp_HuGas - Isentropic exponent

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ 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 ($\psi_w > \psi_{w,sat}$, $t < 0.01\text{ °C}$) as saturated humid gas mixture

Result for incorrect input values:

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 ₂ O	[26]	[31]
SO ₂	[26]	-

Thermal Conductivity $\lambda = f(p, t, \text{type}, \text{comp}(1:8))$
Function Name:

Lambda_ptcomp_HuGas

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

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 CO₂ and SO₂ less than saturation pressures

Comments:

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

Result for incorrect input values:

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 ₂ O	[16]
SO ₂	[34],[35],[40]

Molar Mass $M = f(\text{type}, \text{comp}(1:8))$ **Function Name:**

M_comp_HuGas

Input values:

type = 0 → composition as mole fraction

= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

M_comp_HuGas - Molar mass in kg/kmol

Result for incorrect input values:

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

Kinematic Viscosity $\nu = f(p, t, \text{type}, \text{comp}(1:8))$
Function Name:

Ny_ptcomp_HuGas

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:Ny_ptcomp_HuGas - Kinematic viscosity in m²/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 CO₂ and SO₂ less than saturation pressures

Comments:

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

Result for incorrect input values:Ny_ptcomp_HuGas = $-1 \cdot 10^{100}$ **Reference:**

Gas	ν - ideal part	ν - 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 ₂ O	[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
 $type = 1 \rightarrow$ composition as mass fraction
 $comp$ - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

p_hscomp_HuGas - Pressure in bar

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ 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 ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Pressure $p = f(t, s, \text{type}, \text{comp}(1:8))$
Function Name:

p_tscomp_HuGas

Input values:

t - Temperature t in °C
 s - Specific entropy s in kJ/(kg K)
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

p_tscomp_HuGas - Pressure in bar

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Iteration of p from $s(p, t, \text{comp})$ and calculation:
 - for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w, \text{sat}}$) as ideal mixture of real gases (dry gas and steam)
 - for fog ($\psi_w > \psi_{w, \text{sat}}$) 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 ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Saturation Pressure of Water $p_{\text{dsat}} = f(p, t)$
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:

$p_{\text{dsat}}(p, t)$ 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:

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

Reference:

$p_{\text{dsat}}(p, t)$ for $t \geq 0.01$ °C from IAPWS-IF97 [1], [2], [3], [4]
 $p_{\text{dsat}}(p, t)$ for $t < 0.01$ °C from IAPWS-92 [24]

Relative Humidity $\varphi = f(p, t, \text{type}, \text{comp}(1:8))$
Function Name:

Phi_ptcomp_HuGas

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

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 CO₂ and SO₂ less than saturation pressures

Comments:

$$\text{Relative humidity } \varphi = \frac{\frac{X_w}{\frac{R_l}{R_w} + X_w}}{\frac{p}{p_{\text{dsat}}(p, t)}} \cdot 100\%$$

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

Result for incorrect input values:Phi_ptcomp_HuGas = $-1 \cdot 10^{100}$ **Reference:**

$p_{\text{dsat}}(p, t)$ for $t \geq 0.01$ °C from IAPWS-IF97 [1], [2], [3], [4]
 $p_{\text{dsat}}(p, t)$ for $t < 0.01$ °C from IAPWS-92 [24]

Prandtl Number $Pr = f(p, t, \text{type}, \text{comp}(1:8))$
Function Name:

Pr_ptcomp_HuGas

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

Pr_ptcomp_HuGas - Prandtl-number

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 CO₂ and SO₂ less than saturation pressures

Comments:

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

Result for incorrect input values:

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 ₂ O	[26]	[31]	[17]	[16]
SO ₂	[26]	-	[34]	[34],[35],[40]

Gas Constant $R = f(\text{type}, \text{comp}(1:8))$ **Function Name:**

R_comp_HuGas

Input values:

type = 0 → composition as mole fraction

= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)**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, N₂, O₂, CO, CO₂, H₂O, SO₂)

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	= 10 → The CO ₂ in the gas mixture would be partly liquid. Calculation is terminated.
= 4 → Ice fog	
= 5 → Liquid-ice fog at 0.01 °C exactly	= 11 → The SO ₂ in the gas mixture would be partly liquid. Calculation is terminated.

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ 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 ₂ O	[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, N₂, O₂, CO, CO₂, H₂O, SO₂)

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	= 10 → The CO ₂ in the gas mixture would be partly liquid. Calculation is terminated.
= 4 → Ice fog	
= 5 → Liquid-ice fog at 0.01 °C exactly	= 11 → The SO ₂ in the gas mixture would be partly liquid. Calculation is terminated.

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ 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 ₂ O	[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, N₂, O₂, CO, CO₂, H₂O, SO₂)

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	= 10 → The CO ₂ in the gas mixture would be partly liquid. Calculation is terminated.
= 4 → Ice fog	
= 5 → Liquid-ice fog at 0.01 °C exactly	= 11 → The SO ₂ 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 CO₂ and SO₂ 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	<i>s</i> - ideal part	<i>s</i> - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[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
 $type = 0 \rightarrow$ composition as mole fraction
 $= 1 \rightarrow$ composition as mass fraction
 $comp$ - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

Region_ptcomp_HuGas - State point of humid gas mixture

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

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ 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, N₂, O₂, CO, CO₂, H₂O, SO₂)

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	= 10 → The CO ₂ in the gas mixture would be partly liquid. Calculation is terminated.
= 4 → Ice fog	
= 5 → Liquid-ice fog at 0.01 °C exactly	= 11 → The SO ₂ 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 CO₂ and SO₂ 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	<i>s</i> - ideal part	<i>s</i> - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

Density $\rho = f(p, t, \text{type}, \text{comp}(1:8))$
Function Name:

rho_ptcomp_HuGas

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

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 CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values: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 ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Specific Entropy $s = f(p, h, \text{type}, \text{comp}(1:8))$
Function Name:

s_phcomp_HuGas

Input values:

p - Pressure p in bar
 h - Specific enthalpy h in kJ/kg
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

s_phcomp_HuGas - Specific entropy in kJ/(kg K)

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Iteration of t from $h(p, t, \text{comp})$ and calculation of s from $s(p, t, \text{comp})$

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,\text{sat}}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,\text{sat}}$) 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 ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Specific Entropy $s = f(p, t, \text{type}, \text{comp}(1:8))$
Function Name:

s_ptcomp_HuGas

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

s_ptcomp_HuGas - Specific entropy in kJ/(kg K)

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,\text{sat}}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,\text{sat}}$) 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 ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Surface Tension of Water $\sigma_w = f(t)$
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 : $0\text{ °C} \leq t \leq 373.946\text{ °C}$

Comments:

Calculation for pure water from IAPWS-IF97

Result for incorrect input values:

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)
 $type = 0 \rightarrow$ composition as mole fraction
 $= 1 \rightarrow$ composition as mass fraction
 $comp$ - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

t_hscomp_HuGas - Temperature t in °C

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ 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 ₂ O	[26]	[31]
SO ₂	[26]	-

Temperature $t = f(p, h, \text{type}, \text{comp}(1:8))$
Function Name:

t_phcomp_HuGas

Input values:

p - Pressure p in bar
 h - Specific enthalpy h in kJ/kg
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

t_phcomp_HuGas - Temperature in °C

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Iteration of t from $h(p, t, \text{comp})$

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,\text{sat}}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,\text{sat}}$) 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 ₂ O	[26]	[31]
SO ₂	[26]	-

Temperature $t = f(p, s, \text{type}, \text{comp}(1:8))$
Function Name:

t_pscomp_HuGas

Input values:

p - Pressure p in bar
 s - Specific entropy s in kJ/(kg K)
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

t_pscomp_HuGas - Temperature t in °C

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Iteration of t from $s(p, t, \text{comp})$

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,\text{sat}}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,\text{sat}}$) 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 ₂ O	[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
 $type = 1 \rightarrow$ composition as mass fraction
 $comp$ - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

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

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Result for incorrect input values:

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

References:

$t_s(p, p_d)$ for $t \geq 0.01\text{ °C}$ from IAPWS-IF97 [1], [2], [3], [4]
 $t_{sub}(p, p_d)$ for $t < 0.01\text{ °C}$ from IAPWS-92 [24]

Internal Energy $u = f(p, t, \text{type}, \text{comp}(1:8))$
Function Name:

u_ptcomp_HuGas

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

u_ptcomp_HuGas - Internal energy in kJ/kg

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,\text{sat}}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,\text{sat}}$) 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 ₂ O	[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)
 $type = 0 \rightarrow$ composition as mole fraction
 $type = 1 \rightarrow$ composition as mass fraction
 $comp$ - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

`v_hscomp_HuGas` - Specific volume in m³/kg

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ 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 ₂ O	[26]	[31]
SO ₂	[26]	-

Specific Volume $v = f(p, h, \text{type}, \text{comp}(1:8))$
Function Name:

`v_phcomp_HuGas`

Input values:

p - Pressure p in bar
 h - Specific enthalpy h in kJ/kg
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

`v_phcomp_HuGas` - Specific volume in m³/kg

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 CO₂ and SO₂ less than saturation pressures

Comments:

Iteration of t from $h(p, t, \text{comp})$ and calculation of v from $v(p, t, \text{comp})$

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w, \text{sat}}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w, \text{sat}}$) 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 ₂ O	[26]	[31]
SO ₂	[26]	-

Specific Volume $v = f(p, s, \text{type}, \text{comp}(1:8))$
Function Name:

`v_pscomp_HuGas`

Input values:

p - Pressure p in bar
 s - Specific entropy s in kJ/(kg K)
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

`v_pscomp_HuGas` - Specific volume in m³/kg

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Iteration of t from $s(p, t, \text{comp})$ and calculation of v from $v(p, t, \text{comp})$

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w, \text{sat}}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w, \text{sat}}$) 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 ₂ O	[26]	[31]
SO ₂	[26]	-

Specific Volume $v = f(p, t, \text{type}, \text{comp}(1:8))$
Function Name:

v_ptcomp_HuGas

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:v_ptcomp_HuGas - Specific volume in m³/kg**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 CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,\text{sat}}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,\text{sat}}$) 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 ₂ O	[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)
 $type = 0 \rightarrow$ composition as mole fraction
 $type = 1 \rightarrow$ composition as mass fraction
 $comp$ - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

`v_tscomp_HuGas` - Specific volume in m³/kg

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 CO₂ and SO₂ 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 ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Isentropic Speed of Sound $w = f(p, t, \text{type}, \text{comp}(1:8))$
Function Name:

w_ptcomp_HuGas

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

w_ptcomp_HuGas - Isentropic speed of sound in m/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 CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

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

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

- for liquid fog ($\psi_w > \psi_{w,\text{sat}}$) as ideal mixture of saturated humid gas and liquid water- for ice fog ($\psi_w > \psi_{w,\text{sat}}$, $t < 0.01$ °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 ₂ O	[26]	[31]
SO ₂	[26]	-

Humidity Ratio (Absolute Humidity) $x_w = f(\text{type}, \text{comp}(1:8))$
Function Name:

xw_comp_HuGas

Input values:

type = 0 → composition as mole fraction

= 1 → composition as mass fraction

comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

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

Comments:

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

Result for incorrect input values:

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

Mole Fraction of Liquid Water $\psi_{wl} = f(p, t, \text{type}, \text{comp}(1:8))$
Function Name:

Psiwl_ptcomp_HuGas

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 $\text{type} = 0 \rightarrow$ composition as mole fraction
 $\text{type} = 1 \rightarrow$ composition as mass fraction
 comp - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

Psiwl_ptcomp_HuGas - Mole fraction of water in kmol/kmol

Range of validity:

Temperature t : $t_t(p, \text{comp}) \leq t \leq t_s(p, p_d)$
 (t_s – Saturation temperature of water in gas mixtures)
 Pressure p : $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Comments:

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

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

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

Result for incorrect input values:Psiwl_ptcomp_HuGas = $-1 \cdot 10^{100}$ **Reference:**

$p_{dsat}(p, t)$ for $t \geq 0.01 \text{ °C}$ from IAPWS-IF97 [1], [2], [3], [4]
 $p_{dsat}(p, t)$ for $t < 0.01 \text{ °C}$ 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
 $type = 1 \rightarrow$ composition as mass fraction
 $comp$ - Vector of composition (Ar, Ne, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

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

Range of validity:

Temperature t : $-70\text{ °C} \leq t \leq t_s(p, p_d)$
 (t_s – Saturation temperature of water in gas mixtures)
 Pressure p : $0.01\text{ bar} \leq p \leq 1000\text{ bar}$

Comments:

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

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

Result for incorrect input values:

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

Reference:

$p_{dsat}(p, t)$ for $t \geq 0.01\text{ °C}$ from IAPWS-IF97 [1], [2], [3], [4]
 $p_{dsat}(p, t)$ for $t < 0.01\text{ °C}$ from IAPWS-92 [24]



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

Water and Steam

Library LibIF97

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

Humid Combustion Gas Mixtures

Library LibHuGas

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

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:
• Dry air from Lemmon et al.
• Steam, water and ice from IAPWS-IF97 and IAPWS-06
Consideration of:
• Condensation and freezing of steam
• Dissociation from the VDI 4670
• Poynting effect from ASHRAE RP-1485

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (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 H₂O F₂ Propane
N₂ SO₂ NH₃ Iso-Butane
O₂ H₂ Methane n-Butane
CO H₂S Ethane Benzene
CO₂ OH Ethylene Methanol
Air

Consideration of:
• Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:
• Dissociation from the VDI Guideline 4670

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 Bückner and Wagner (2006)

n-Butane

Library LibButane_n

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

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 **H₂S** **Library LibH2S**

Dinitrogen monoxide **N₂O** **Library LibN2O**

Sulfur dioxide **SO₂** **Library LibSO2**

Acetone **C₃H₆O** **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

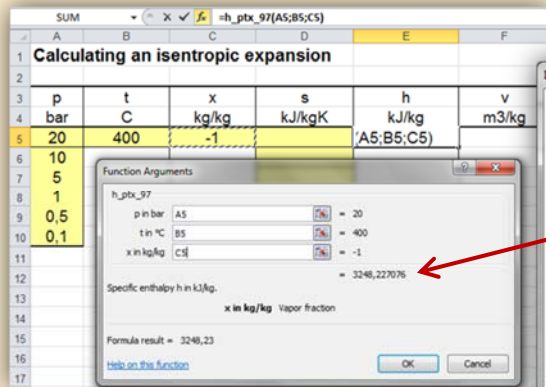
- Partial derivatives can be calculated.

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



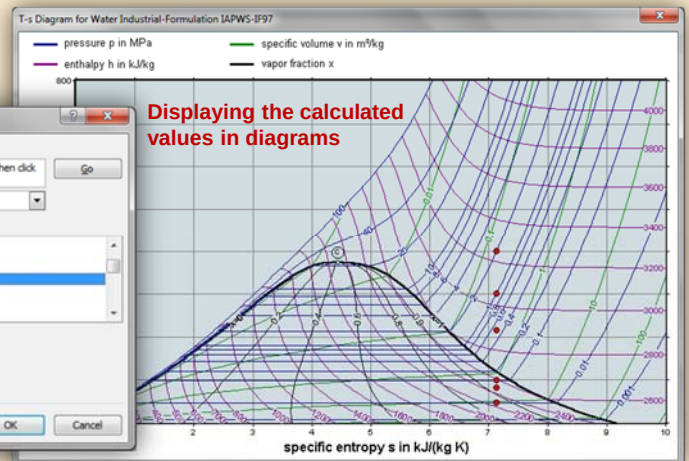
Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

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



Choosing a property library and a function

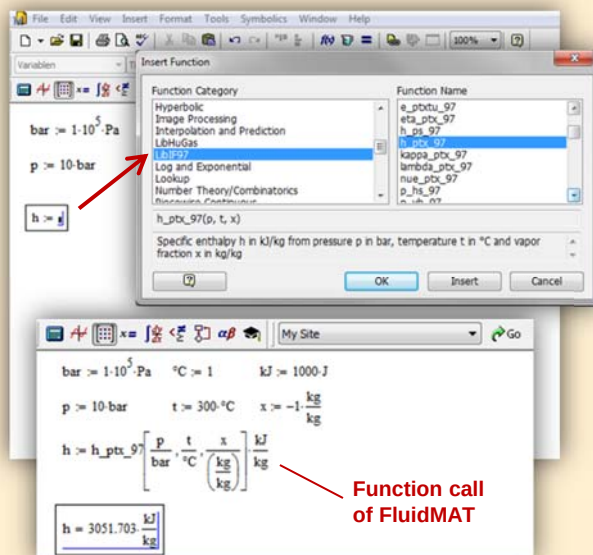
Displaying the calculated values in diagrams



Menu for the input of given property values

Add-In FluidMAT for Mathcad[®]

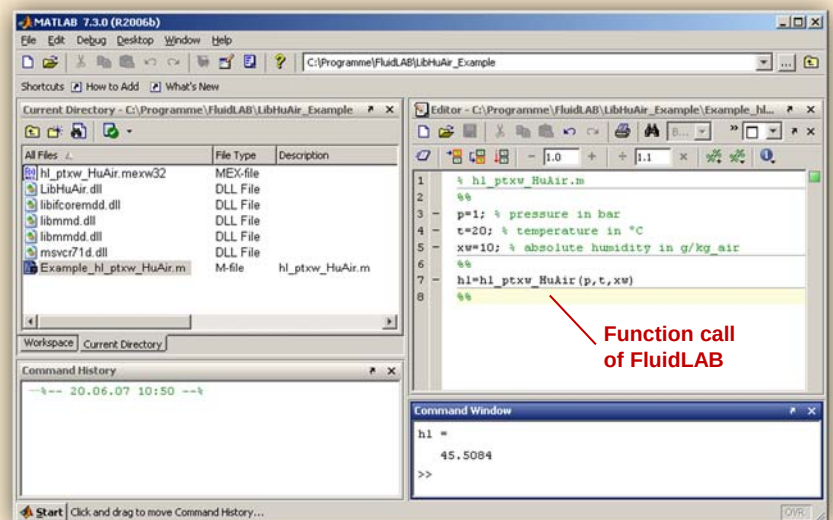
The property libraries can be used in Mathcad[®].



Function call of FluidMAT

Add-In FluidLAB for MATLAB[®]

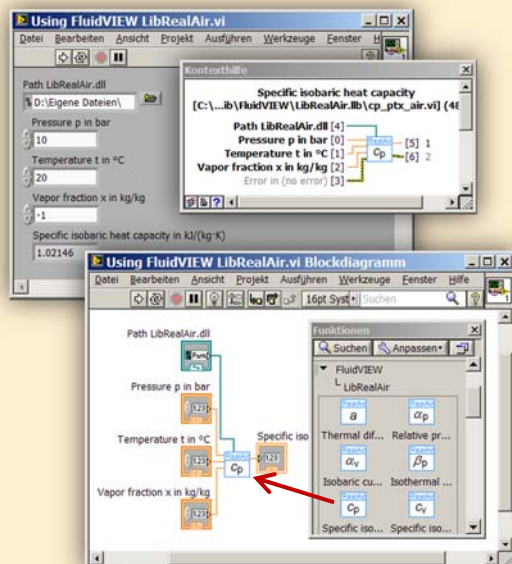
Using the Add-In FluidLAB the property functions can be called in MATLAB[®].



Function call of FluidLAB

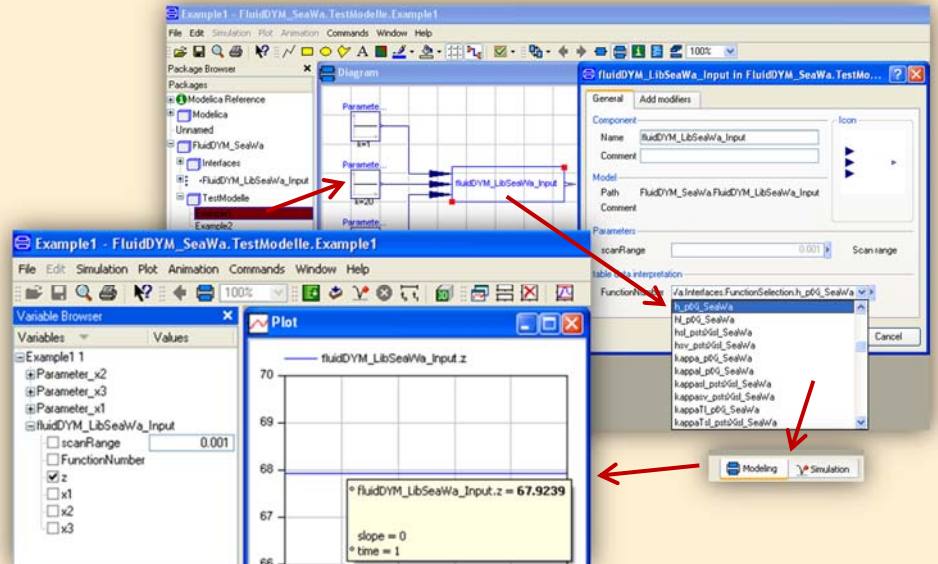
Add-On FluidVIEW for LabVIEW[®]

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

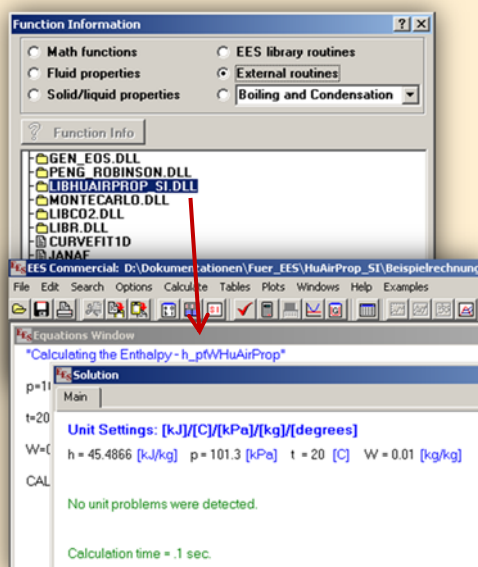


Add-In FluidDYM for DYMOLA[®] (Modelica) and SimulationX[®]

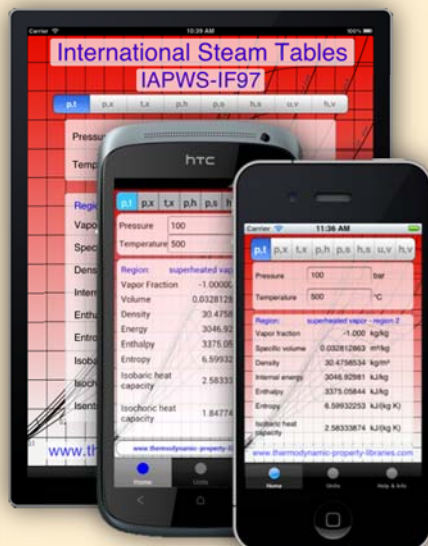
The property functions can be called in DYMOLA[®] and SimulationX[®].



Add-In FluidEES for Engineering Equation Solver®



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



Online Property Calculator at www.thermodynamics-zittau.de

Property Software for Pocket Calculators

FluidCasio



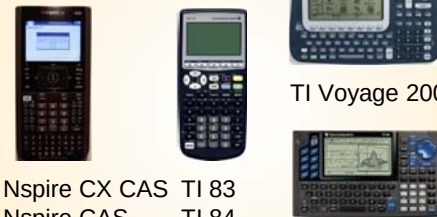
fx 9750 G II CFX 9850 fx-GG20 CFX 9860 G Graph 85 ALGEBRA FX 2.0

FluidHP



HP 48 HP 49

FluidTI



TI Nspire CX CAS TI 83 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.

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Vattenfall Europe (group license)	01/2004
TUEV Nord, Hamburg	01/2004
University of Stuttgart, Institute of Thermodynamics and Heat Engineering	02/2004
MAN B&W Diesel A/S, Copenhagen, Denmark	02/2004
Siemens AG Power Generation, Erlangen	02/2004

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

2003

Paper Factory, Utzenstorf, Switzerland	01/2003
MAB Plant Engineering, Vienna, Austria	01/2003
Wulff Energy Systems, Husum	01/2003
Technip Benelux BV, Zoetermeer, Netherlands	01/2003
ALSTOM Power, Baden, Switzerland	01/2003, 07/2003
VER, Dresden	02/2003
Rietschle Energieplaner, Winterthur, Switzerland	02/2003
DLR, Leupholdhausen	04/2003

Emden University of Applied Sciences, Department of Technology	05/2003
Pettersson+Ahrends, Ober-Moerlen	05/2003
SOFBID ,Zwingenberg (general EBSILON program license)	05/2003
Ingenieurbuero Ostendorf, Gummersbach	05/2003
TUEV Nord, Hamburg	06/2003
Muenstermann GmbH, Telgte-Westbevern	06/2003
University of Cali, Colombia	07/2003
Atlas-Stord, Rodovre, Denmark	08/2003
ENERKO, Aldenhoven	08/2003
STEAG RKB, Leuna	08/2003
eta Energieberatung, Pfaffenhofen	08/2003
exergie, Dresden	09/2003
AWTEC, Zurich, Switzerland	09/2003
Energie, Timelkam, Austria	09/2003
Electrowatt-EKONO, Zurich, Switzerland	09/2003
LG, Annaberg-Buchholz	10/2003
FZR Forschungszentrum, Rossendorf/Dresden	10/2003
EnviCon & Plant Engineering, Nuremberg	11/2003
Visteon, Kerpen	11/2003
VEO Vulkan Energiewirtschaft Oderbruecke, Eisenhuettenstadt	11/2003
Stadtwerke Hannover	11/2003
SaarEnergie, Saarbruecken	11/2003
Fraunhofer-Gesellschaft, Munich	12/2003
Erfurt University of Applied Sciences, Department of Supply Engineering	12/2003
SorTech, Freiburg	12/2003
Mainova, Frankfurt	12/2003
Energieversorgung Halle	12/2003

2002

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

CompAir, Simmern	03/2002
GKS Gemeinschaftskraftwerk, Schweinfurt	04/2002
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InfraServ, Gendorf	05/2002
SoftSolutions, Muehlhausen (company license)	05/2002
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Fischer-Uhrig Engineering, Berlin	08/2002
Fichtner Consulting & IT, Stuttgart (company licenses and distribution)	08/2002
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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

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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
eta Energieberatung, Pfaffenhofen	11/2001
ALSTOM Power Baden, Switzerland	12/2001
VEAG, Berlin (group license)	12/2001

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SOFBID, Zwingenberg (general EBSILON program license)	01/2000
AG KKK - PGW Turbo, Leipzig	01/2000
PREUSSAG NOELL, Wuerzburg	01/2000
M&M Turbine Technology, Bielefeld	01/2000
IBR Engineering Reis, Nittendorf-Undorf	02/2000
GK, Hannover	03/2000
KRUPP-UHDE, Dortmund (company license)	03/2000
UMAG W. UDE, Husum	03/2000
VEAG, Berlin (group license)	03/2000
Thinius Engineering, Erkrath	04/2000
SaarEnergie, Saarbruecken	05/2000, 08/2000
DVO Data Processing Service, Oberhausen	05/2000
RWTH Aachen University	06/2000
VAUP Process Automation, Landau	08/2000
Knuerr-Lommatec, Lommatzsch	09/2000
AVACON, Helmstedt	10/2000
Compania Electrica, Bogota, Colombia	10/2000
G.U.N.T. Geraetebau, Barsbuettel (general license for training test benches)	11/2000
Steinhaus Informationssysteme, Datteln (general license for process data software)	12/2000

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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
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Technical University of Graz, Department of Thermal Engineering, Austria	11/1999
Ostendorf Engineering, Gummersbach	12/1999

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Technical University of Cottbus, Chair in Power Plant Engineering	05/1998
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
VEAG Berlin (group license)	09/1998
NUTEC Engineering, Bisikon, Switzerland	10/1998
SCA Hygiene Products, Munich	10/1998
RWE Energie, Neurath	10/1998
Wilhelmshaven University of Applied Sciences	10/1998
BASF, Ludwigshafen (group license)	11/1998
Energieversorgung, Offenbach	11/1998

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