

Property Library for Humid Gas Mixtures

FluidEXL *Graphics*
with LibHuGas
for Excel®

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**Software for the Calculation of the Properties
of Humid Gas Mixtures
Including DLL and Add-In for Excel®
FluidEXL *Graphics*
LibHuGas**

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0 Package Contents

0.1 Zip files for 64-bit Office®

The following zip file has been delivered for your computer running a 64-bit Office® version:

CD_FluidEXL_Graphics_Eng_LibHuGas_x64.zip

including the following folders and files:

\FLUFT\

\Formulation97\

FluidEXL_Graphics_LibHuGas_Docu_Eng.pdf

FluidEXL_Graphics_Eng.xla

LC.dll

LibHuGas.dll

LibHuGas.chm.

0.2 Zip files for 32-bit Office®

The following zip file has been delivered for your computer running a 32-bit Office® version:

CD_FluidEXL_Graphics_Eng_LibHuGas.zip

including the following folders and files:

\FLUFT\

\Formulation97\

FluidEXL_Graphics_LibHuGas_Docu_Eng.pdf

FluidEXL_Graphics_Eng.xla

LC.dll

LibHuGas.dll

LibHuGas.chm.

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

Consideration of Dissociation

For temperatures above 1000 °C and mole fractions of oxygen of more than 1 % ($\psi_{O_2} \geq 0.01$) the dissociation of the gases nitrogen, oxygen, carbon dioxide, steam, and sulfur dioxide based on the VDI 4670 are considered.

In order to achieve smooth transitions in the calculations, between 1 % and 2 % mol fractions of oxygen and between 500 and 501 °C, linear transition functions for the calculations of c_p , c_v , h , and s were built into the programs.

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

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

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

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

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 FluidEXL *Graphics* in Excel®

The FluidEXL *Graphics* Add-In has been developed to calculate thermodynamic properties in Excel® more conveniently. Within Excel®, it enables the direct call of functions relating to Water and Steam from the LibHuGas property program library.

2.1 Installing FluidEXL *Graphics*

Complete the following steps for initial installation of FluidEXL *Graphics*.

Before you begin, it is best to uninstall any older version of FluidEXL *Graphics*.

The installation routine for 32-bit and 64-bit versions of Excel is similar. The following instructions are valid for both versions.

After you have downloaded and extracted the zip-file:

CD_FluidEXL_Graphics_LibHuGas_x64_Eng.zip (for 64 bit version)

or

CD_FluidEXL_Graphics_LibHuGas_Eng.zip" (for 32 bit version).

you will see the folder

\CD_FluidEXL_Graphics_LibHuGas_x64_Eng\ (for 64 bit version)

or

\CD_FluidEXL_Graphics_LibHuGas_Eng\ (for 32 bit version)

in your Windows Explorer, Total Commander etc.

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

Within this folder you will see the following folders and files:

\FLUFT\
 \Formulation97\
 FluidEXL_Graphics_Eng.xla
 FluidEXL_Graphics_LibHuGas_Docu_Eng
 LC.dll
 LibHuGas.dll
 LibHuGas.chm
 Reg_.reg

Now, please copy the following folders and files

\FLUFT\
 \Formulation97\
 FluidEXL_Graphics_Eng.xla
 LibHuGas.dll
 LibHuGas.chm
 LC.dll

into the folder

C:\Users\[your name]\AppData\Roaming\Microsoft\AddIns\
 where [your name] is your name in the Windows system.

If this folder is not found, follow the next section anyway.

2.2 Registering FluidEXL *Graphics* as Add-In in Excel®

After installation in Windows®, FluidEXL *Graphics* must be registered in Excel® as an Add-In. To do this, start Excel® and carry out the following steps:

- Click the "File" button in the upper left hand corner of Excel® (see Fig. 2.1)

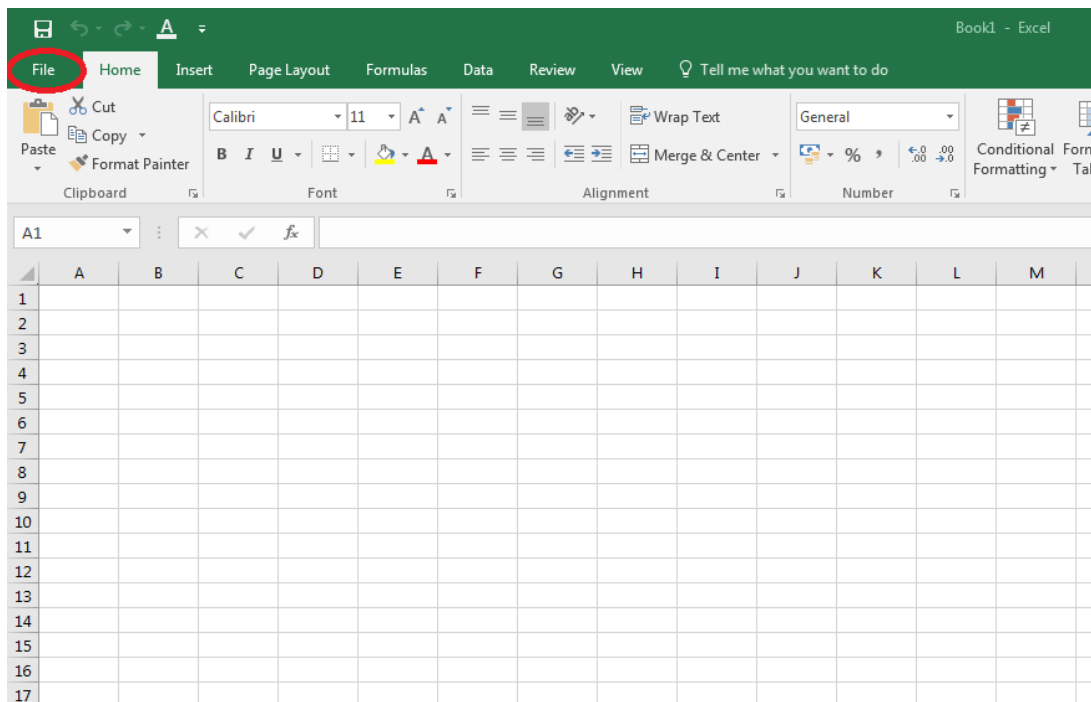


Figure 2.1: Registering FluidEXL *Graphics* as Add-In in Excel® 2016

- Click on the "Options" button in the menu which appears (see Fig. 2.2)

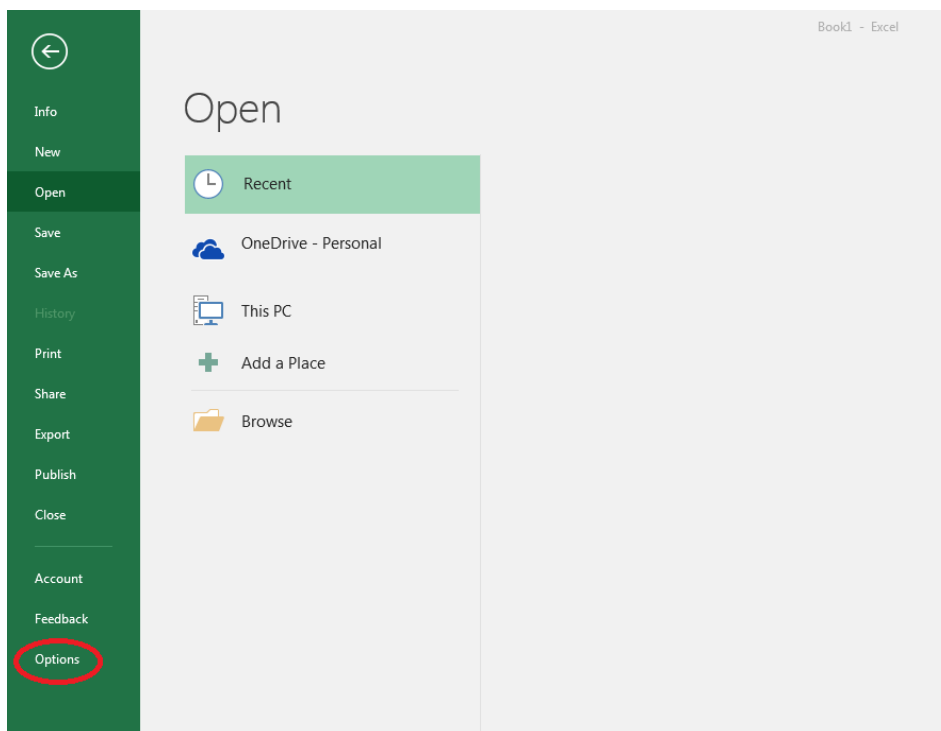


Figure 2.2: Registering FluidEXL *Graphics* as Add-In in Excel® 2016

- Click on "Add-Ins" in the next menu (Fig. 2.3)

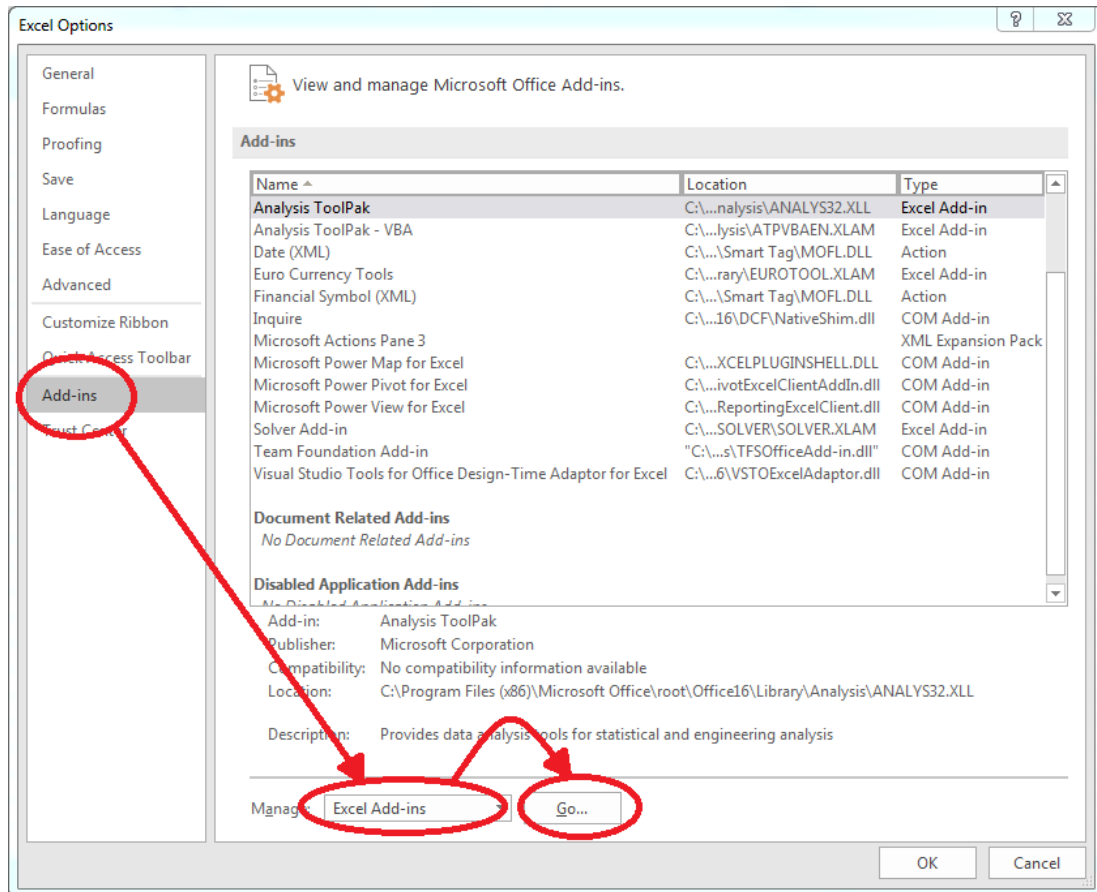


Figure 2.3: Dialog window "Excel Options"

- Select "Excel Add-ins" next to "Manage:" in the lower area of the menu
- Then click the "Go..." button
- Click "Browse" in the following window (Fig. 2.4)

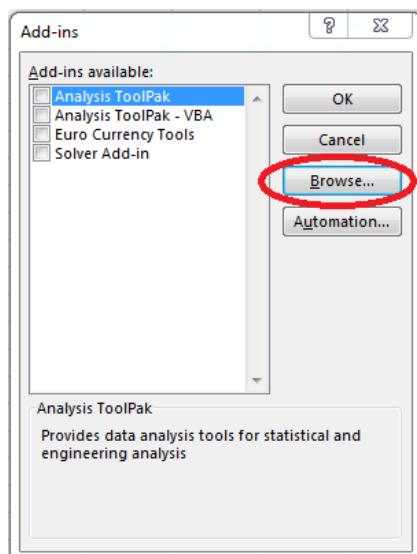


Figure 2.4: Dialog window "Add-ins"

- Excel opens the AddIns folder. This is usually
C:\Users\[your name]\AppData\Roaming\Microsoft\AddIns\.
- If the FluidEXL files have already been copied to this directory in section 2.1, please skip the following indented section. If not, follow the indented instructions to successful paste the needed files for the FluidEXL Add-In:

In the upper part of the "Browse" window the correct Add-In path is displayed (see Figure 2.5). Please note that not the entire path is displayed.

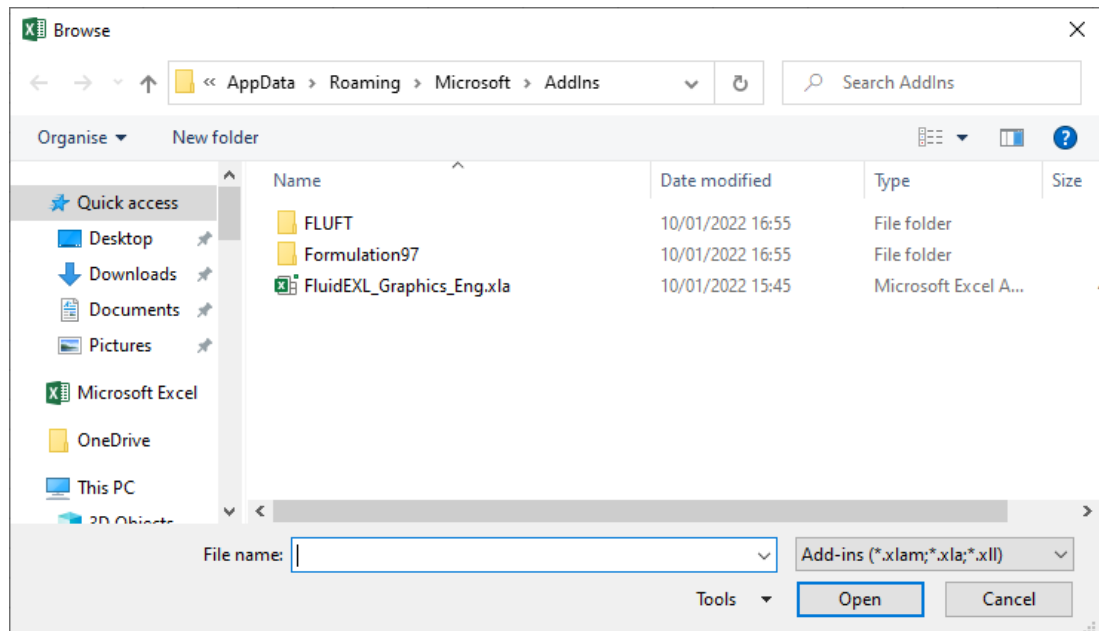


Figure 2.5: "Browse"-Window

Please copy this path and paste it into your file manager.

Now, please copy the following directories and files:

```
\FLUFT\
\Formulation97\
LC.dll
FluidEXL_Graphics_Eng.xla
LibHuGas.dll
LibHuGas.chm
```

from the delivered CD-folder into this folder.

- Click "FluidEXL_Graphics_Eng.xla" in this folder (see Fig. 2.5) and click "OK."
- Now, "FluidEXL Graphics Eng" will be shown in the list of Add-ins (see Fig. 2.6).
(If a checkmark is in the box next to the name "FluidEXL Graphics Eng", this Add-In will automatically be loaded whenever Excel starts. This will continue to occur unless the checkmark is removed from the box by clicking on it.)
- In order to register the Add-In click the "OK" button in the "Add-ins" window (see Fig. 2.6).

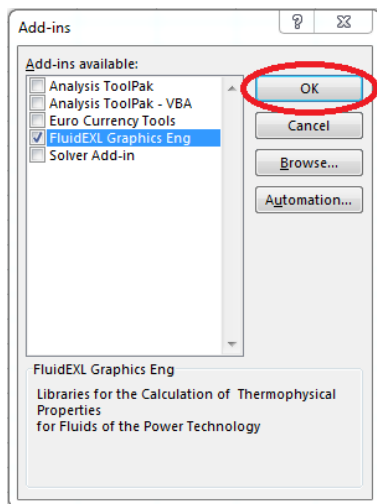


Figure 2.6: Dialog window "Add-Ins"

In order to use FluidEXL *Graphics* in the following example, click on the menu item "Add-Ins" shown in Fig. 2.7.

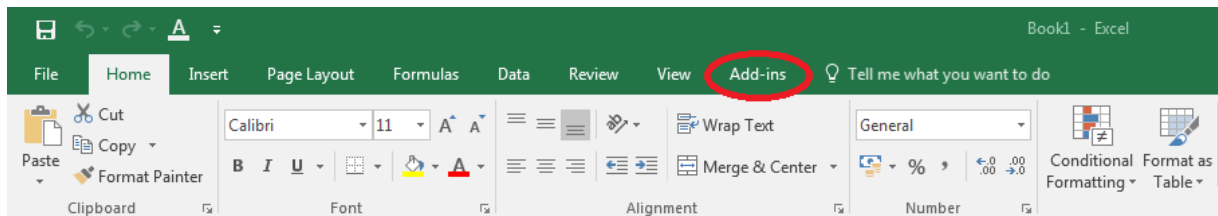


Figure 2.7: Menu item "Add-Ins"

In the upper menu region of Excel®, the FluidEXL *Graphics* menu bar will appear as marked with the red circle in Fig. 2.8.

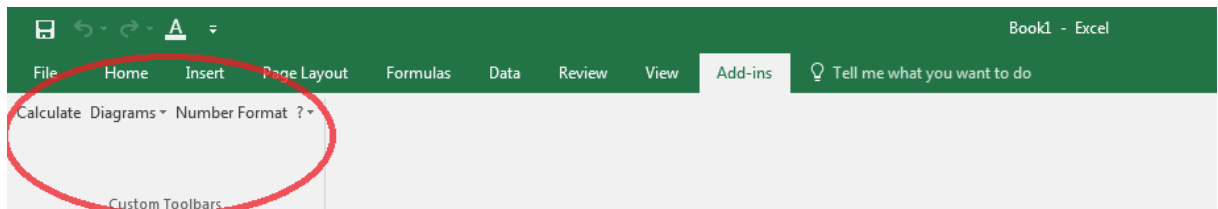


Figure 2.8: FluidEXL *Graphics* menu bar

The Installation of FluidEXL *Graphics* in Excel® is now complete.

An example calculation of "LibHuGas" DLL library property functions can be found in chapter 2.4.

2.3 Licensing the LibHuGas Property LibHuGasrary

The licensing procedure has to be carried out when Excel® starts up and a FluidEXL *Graphics* prompt message appears. In this case, you will see the "License Information" window (see figure below).

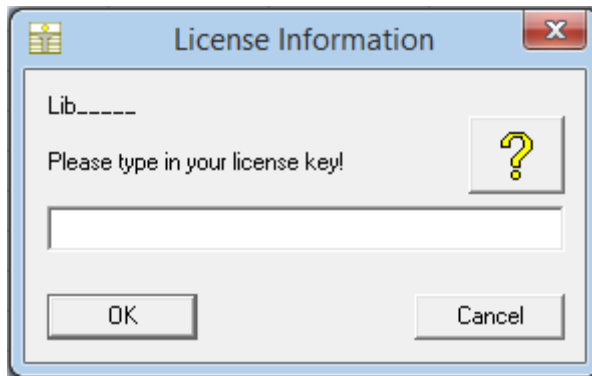


Figure 2.12: "License Information" window

Here you will have to type in the license key. 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:

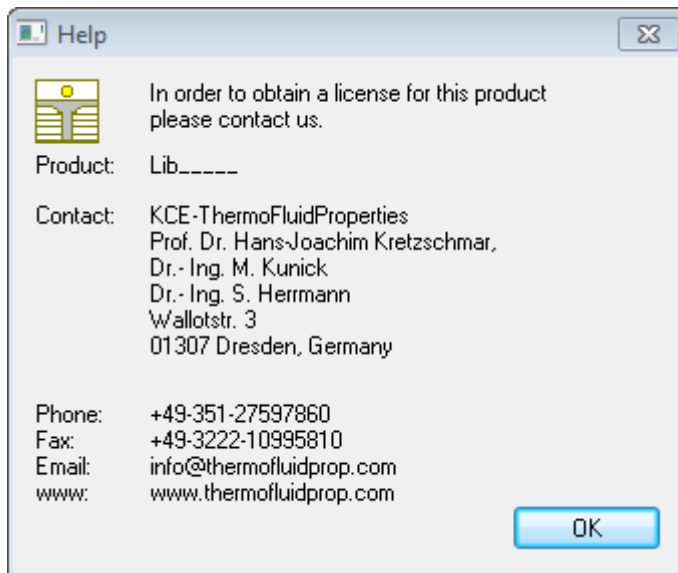


Figure 2.13: "Help" window

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

The "License Information" window will appear every time you start Excel® unless you uninstall FluidEXL^{Graphics} according to the description in section 2.6 of this User's Guide.

Should you not wish to license the LibHuGas property library, you have to delete the files
LibHuGas.dll
LibHuGas.chm

in the installation folder of FluidEXL^{Graphics} (the standard being)

C:\Program Files\FluidEXL_Graphics_Eng
using an appropriate program such as Explorer® or Norton Commander.

Note:

The product name "LibHuGas_ _ _ _" in Figure 2.12 and 2.13 stands for the LibHuGasrary you are installing. In this case it is the LibHuGas library.

2.4 Example calculation

Now we will calculate, step by step, the specific enthalpy h as function of pressure, temperature, type (composition as mole or mass fractions) and composition vector using FluidEXL *Graphics*.

The description is based on Excel® 2000. But the instructions are similar in Excel 97, XP, and 2007. Carry out the following steps:

- Start Excel®
- Prepare a worksheet as shown in Figure 2.9

	A	B	C	D	E
1	Input:				
2	Pressure		p=		bar
3	Temperature		t=		°C
4	Type		type=		
5	composition	Ar	Psi=		kmol/kmol
6		Ne	Psi=		kmol/kmol
7		N2	Psi=		kmol/kmol
8		O2	Psi=		kmol/kmol
9		CO	Psi=		kmol/kmol
10		CO2	Psi=		kmol/kmol
11		H2O	Psi=		kmol/kmol
12		SO2	Psi=		kmol/kmol
13					
14	Output:				
15	Specific Enthalpy		h(p,t,comp)=		kJ/kg
16					

Figure 2.9: Example worksheet for the calculation of specific enthalpy

- Enter the value for pressure p in bar into a cell
(Range of validity of LibHuGas: $p = 0.01$ bar ... 1000 bar)
⇒ e.g.: Enter the value 10 into cell D2
- Enter the value for temperature t in °C in a cell
(Range of validity of LibHuGas: $t = -70$ °C ... 3026.15 °C)
⇒ e.g.: Enter the value 500 into cell D3
- Enter the value for type into a cell
(Definition of type: 0 – composition as mole fractions
1 – composition as mass fractions)
⇒ e.g.: Enter the value 0 into cell D4
- Enter the composition vector into 8 successive cells, either within a column or within a row

ψ_1 for Argon	Ar	⇒ e.g.: Enter the value 0.0088 in Cell D5
ψ_2 for Neon	Ne	⇒ e.g.: Enter the value 0 in Cell D6
ψ_3 for Nitrogen	N2	⇒ e.g.: Enter the value 0.7480 in Cell D7
ψ_4 for Oxygen	O2	⇒ e.g.: Enter the value 0.1352 in Cell D8
ψ_5 for Carbon monoxide	CO	⇒ e.g.: Enter the value 0 in Cell D9
ψ_6 for Carbon dioxide	CO2	⇒ e.g.: Enter the value 0.0330 in Cell D10
ψ_7 for Water	H2O	⇒ e.g.: Enter the value 0.0750 in Cell D11
ψ_8 for Sulfur dioxide	SO2	⇒ e.g.: Enter the value 0 in Cell D12

The Excel sheet should now look as shown in Figure 2.10.

	A	B	C	D	E
1	Input:				
2	Pressure		p=	10	bar
3	Temperature		t=	500	°C
4	Type		type=	0	
5	composition	Ar	Psi=	0.0088	kmol/kmol
6		Ne	Psi=	0	kmol/kmol
7		N2	Psi=	0.7480	kmol/kmol
8		O2	Psi=	0.1352	kmol/kmol
9		CO	Psi=	0	kmol/kmol
10		CO2	Psi=	0.0330	kmol/kmol
11		H2O	Psi=	0.0750	kmol/kmol
12		SO2	Psi=	0	kmol/kmol
13					
14	Output:				
15	Specific Enthalpy		h(p,t,comp)=		kJ/kg
16					

Figure 2.10: Example sheet after input of the given parameters

- Click the cell in which the calculated enthalpy h in kJ/kg is to be displayed
⇒ e.g.: [Click the cell D15](#)
- Click "Calculate" in the menu bar of FluidEXL *Graphics*
Now the "Insert Function" window appears.
- Search and click the "Humid Gas LibHuGas" library under "Or select a category:"
(see Figure 2.11)
- Search and click the "h_ptcomp_HuGas" function under "Select a function:"

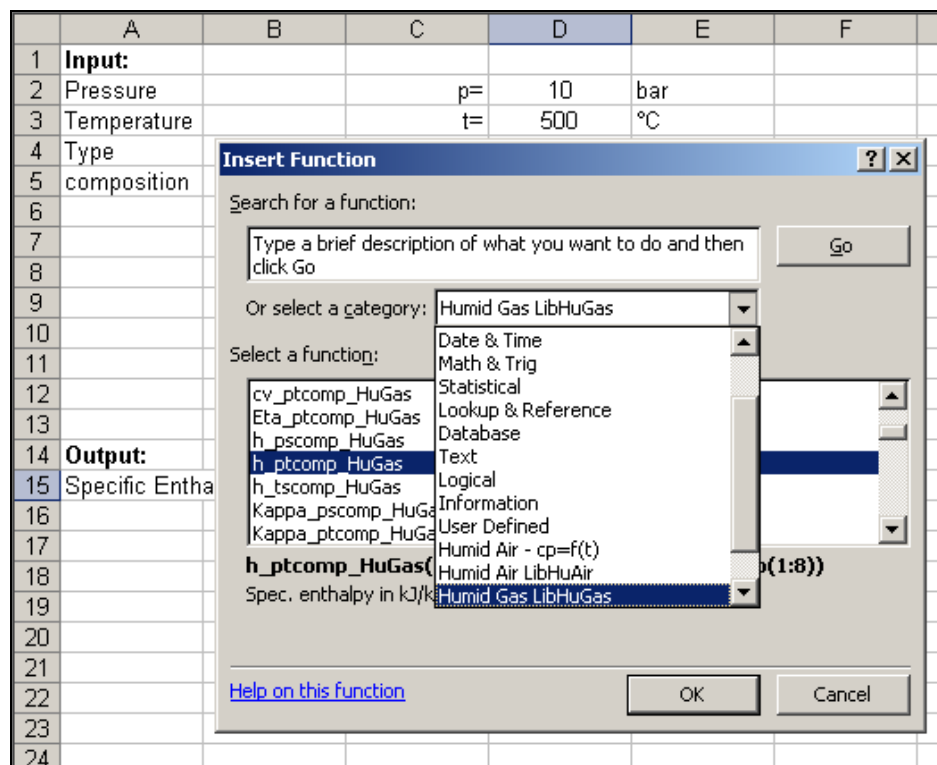


Figure 2.11: Choice of library and function name

- Click the "OK" button
The "Function Arguments" window will now appear (Figure 2.12).

Function Arguments

h_ptcomp_HuGas

P in bar

T in °C

1->Xi 0->Psi

Comp(1:8)

Spec. enthalpy in kJ/kg. =

P in bar Pressure.

Formula result =

[Help on this function](#) OK Cancel

Figure 2.12: Input menu for the function h_ptcomp_HuGas

- The cursor is situated on the line next to "P in bar". You can now enter the value for p either by clicking the cell with the value for p , by entering the name of the cell with the value for p , or by entering the value for p directly.
⇒ e.g.: Click on cell D2
 - Situate the cursor on the line next to "T in °C". You can now enter the value for t either by clicking the cell with the value for t , by entering the name of the cell with the value for t , or by entering the value for t directly.
⇒ e.g.: Type D3 into the window next to "t in °C"
 - Situate the cursor on the line next to "1→Xsi 0→Psi". You can now enter the value for type either by clicking the cell with the value for type, by entering the name of the cell with the value for type, or by entering the value for type directly.
type = 0 for input of mole fractions
type = 1 for input of mass fractions
⇒ e.g.: Click on cell D4
 - Situate the cursor on the line next to "comp(1:8)". Now the composition as mole or mass fractions must be entered.
 - Click on the cell including the mole or mass fraction of the first gas Ar
⇒ e.g.: Click the cell D5
 - The mouse arrow changes into a cross.
By pressing the left mouse button, mark the other cells including mole or mass fractions for Ne, N₂, O₂, CO, CO₂, H₂O and SO₂ and let the mouse button go after that.
⇒ e.g.: Mark the cells D5 to D12 by pressing the left mouse button and let the mouse button go
The marked range "D5:D12" appears in the window next to "comp(1:8)".
- Alternatively, the range can be set directly by entering the numbers of the first and last cells separated by a colon in the window next to "comp(1:8)", for example enter "D5:D12".

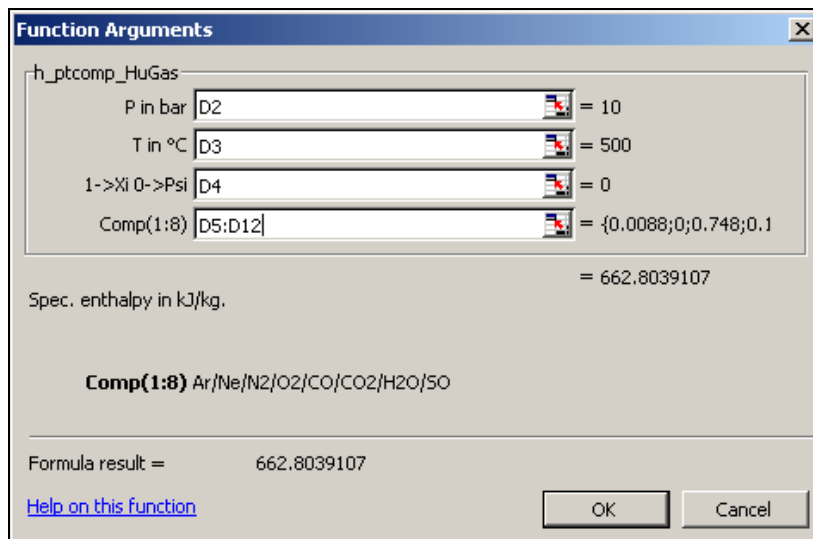


Figure 2.13: Input menu showing the result

- Click "OK"
The result for h in kJ/kg appears in the cell selected above.
⇒ The result in our sample calculation here is: $h = 662.8039107$ kJ/kg.

The calculation of $h = f(p, t, \text{type}, \text{comp}(1:8))$ has thus been completed.

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

Number Formats

When using FluidEXL *Graphics* you have the option of choosing special number formats in advance.

Changes can be made as follows:

- Click the cell or select and click on the cells you wish to format.
(In empty cells the new format will be applied once a value has been entered.)
- Click "Number Format" in the FluidEXL *Graphics* menu bar.
- Select the desired number format in the dialog box which appears:

"STD – Standard":	Insignificant zeros behind the decimal point are not shown.
"FIX – Fixed Number of Digits":	All set decimal places are shown, including insignificant zeros.
"SCI – Scientific Format":	Numbers are always shown in the exponential form with the set number of decimal places.
- Set the "Number of decimal places" by entering the number into the appropriate window.
- Confirm this by clicking the "OK" button.

As an example, the table below shows the three formats for the number 1.230 adjusted for three decimal places:

STD	1.23
FIX	1.230
SCI	1.230E+00

This formatting can also be applied to cells which have already been calculated.

2.5 The FluidEXL *Graphics* Help System

As mentioned earlier, FluidEXL *Graphics* also provides detailed help functions.

Information on individual property functions may be accessed via the following steps:

- Click "Calculate" in the FluidEXL *Graphics* menu bar.
- Click on the "LibHuGas" library under "Or select a category:" in the "Insert Function" window which will appear.
- Click the "Help on this function" button in the lower left-hand edge of the "Insert Function" window.

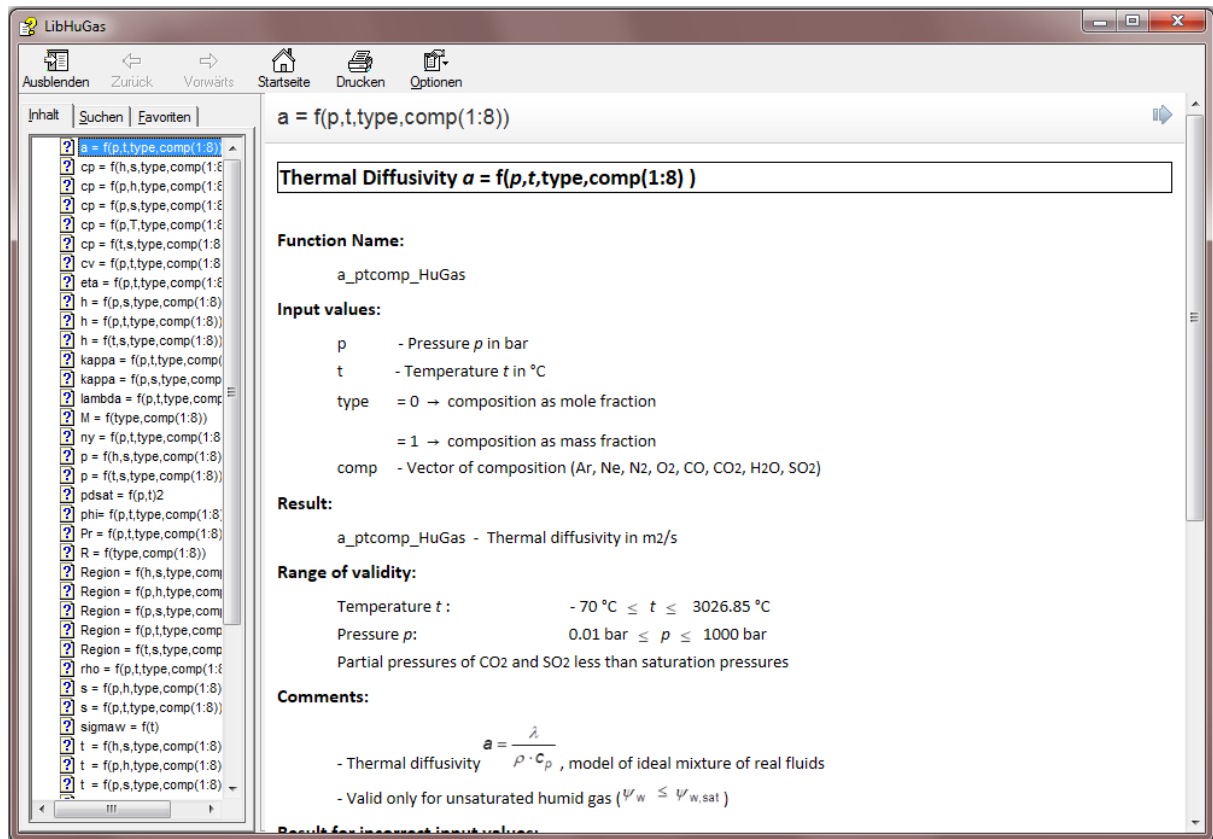


Figure 2.14: Help Window

If the LibHuGas.chm function help cannot be found, you will be redirected to a Microsoft® help website by your standard browser. In this case, the LibHuGas.chm file has to be copied into the folder of FluidEXL *Graphics*, in the standard case

C:\Program Files\FluidEXL_Graphics_Eng

to use the help system.

2.6 Removing FluidEXLGraphics

2.6.1 Removing LibHuGas Library

Should you wish to remove only the LibHuGas library, delete the files

LibHuGas.dll
LibHuGas.chm

in the directory selected for the installation of FluidEXL *Graphics*, in the standard case,

C:\Program Files\FuildEXL_Graphics_Eng

by using an appropriate program such as Explorer® or Norton Commander.

2.6.2 Unregistering and uninstalling FluidEXL *Graphics* as Add-In in versions of Excel® from 2007 onwards (for earlier versions see 2.6.3)

In order to unregister the FluidEXL *Graphics* Add-In in versions of Excel® from 2007 onwards start Excel® and carry out the following commands:

- Click the "File" button in the upper left corner of Excel®
- Click on the "Options" button in the menu which appears

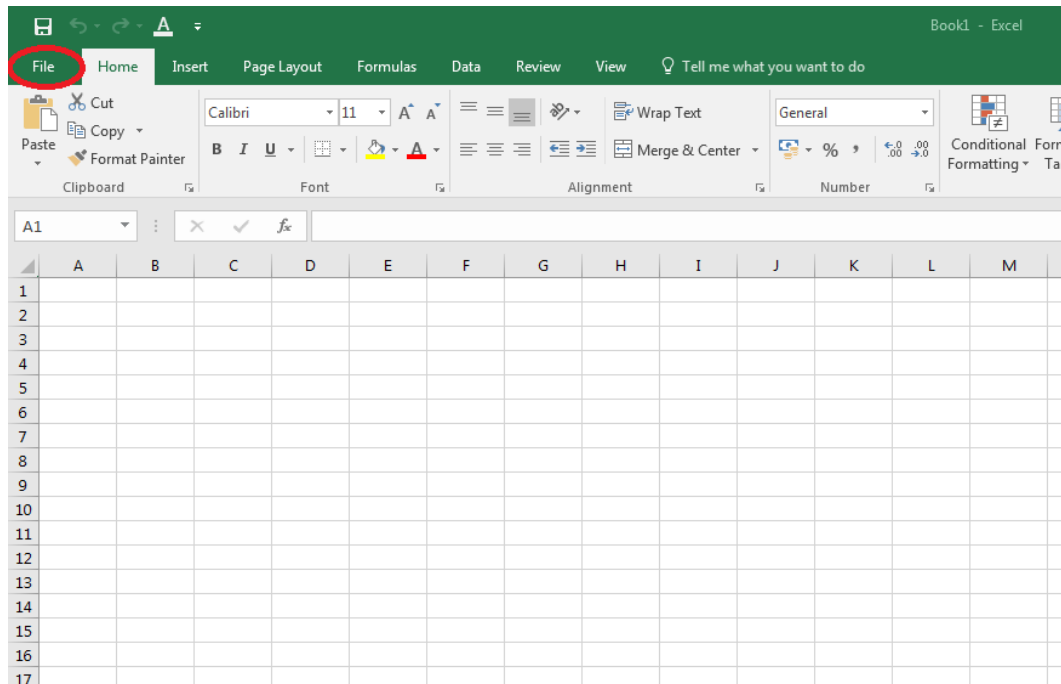


Figure 2.15: Unregistering FluidEXL *Graphics* as Add-In in Excel® 2016

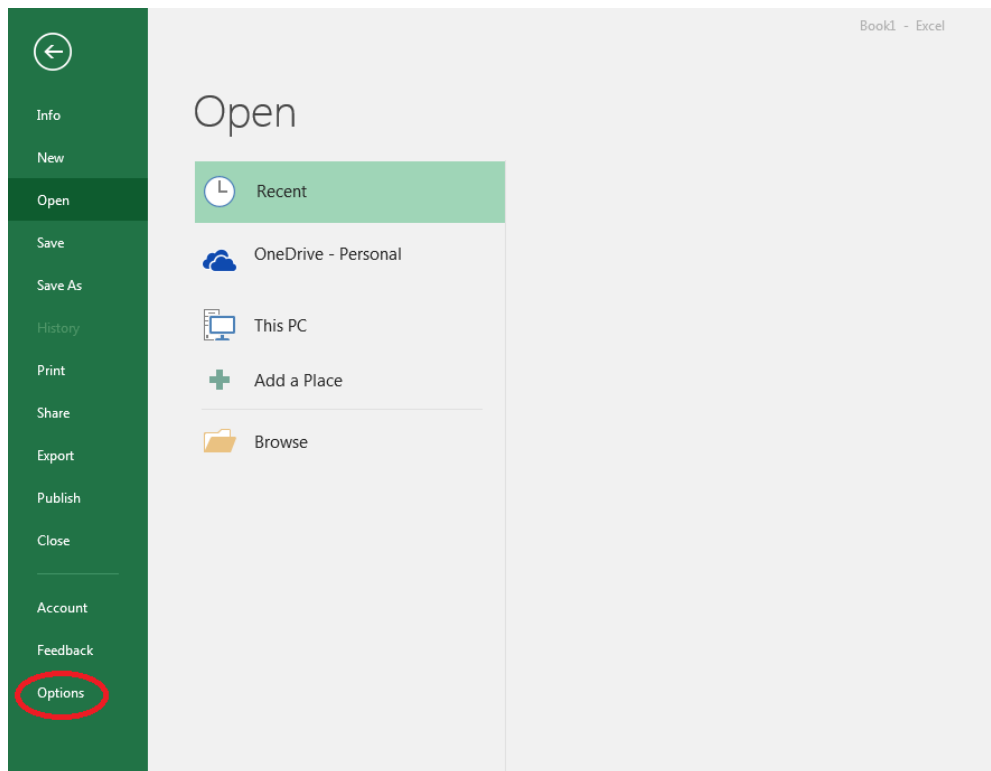


Figure 2.16 Unregistering FluidEXL *Graphics* as Add-In in Excel® 2016

- Click on "Add-Ins" in the next menu (Figure 2.17)

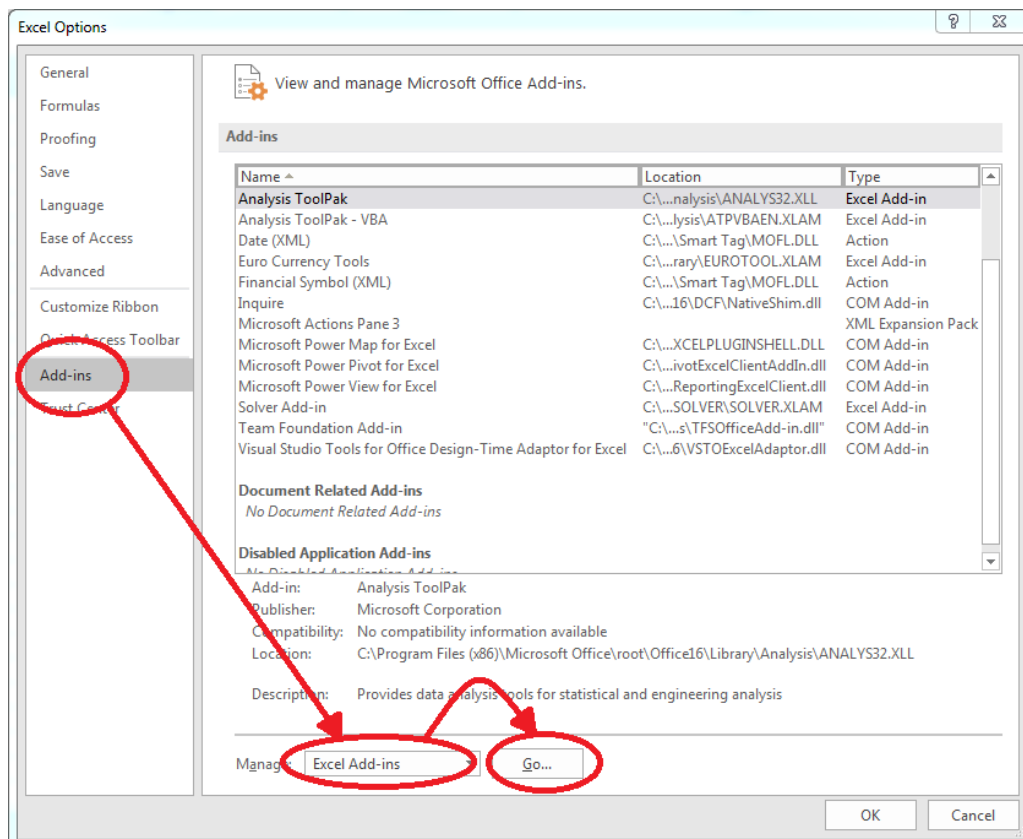


Figure 2.17: Dialog window "Add-Ins"

- If it is not shown in the list automatically, chose and click "Excel Add-ins" next to "Manage:" in the lower area of the menu

- Afterwards click the "Go..." button
- Remove the checkmark in front of "FluidEXL Graphics Eng" in the window which now appears. Click the "OK" button to confirm your entry.

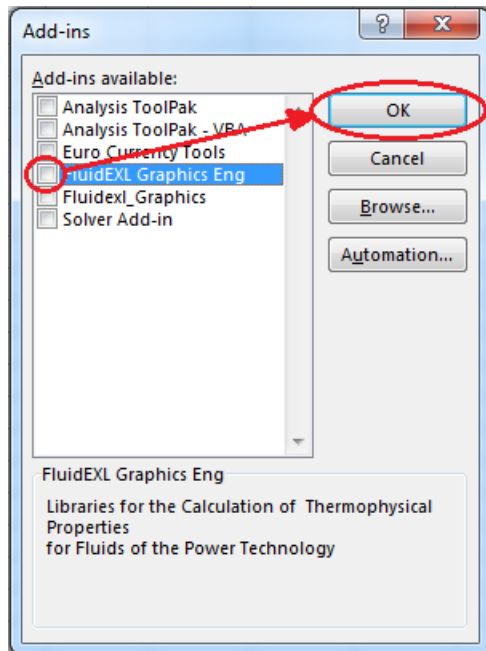


Figure 2.18: Dialog window "Add-Ins"

In order to remove FluidEXL *Graphics* from Windows and the hard drive, 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 "FluidEXL Graphics Eng"

by clicking on it and then clicking the "Add/Remove..." button.

Click "Automatic" in the following dialog box and then the "Next >" button.

Click "Finish" in the "Perform Uninstall" window.

Answer the question of whether all shared components should be removed with "Yes to All." Finally, close the "Add or Remove Programs" and "Control Panel" windows.

Now FluidEXL *Graphics* has been completely removed from your computer.

2.6.3 Unregistering and uninstalling FluidEXL *Graphics* as Add-In in Excel®, versions 2003 or earlier

To remove FluidEXL *Graphics* completely, proceed as follows: First the registration of FluidEXL_Graphics_Eng.xla has to be cancelled in Excel®.

In order to do this, click "Tools" in the upper menu bar of Excel® and here "Add-Ins...". Untick the box on the left-hand side of

"FluidEXL Graphics Eng"

in the window that appears and click the "OK" button. The additional menu bar of FluidEXL *Graphics* disappears from the upper part of the Excel® window. Afterwards, we

recommend closing Excel®.

If the FluidEXL *Graphics* menu bar does not disappear, take the following steps:

Click "View" in the upper menu bar of Excel®, then "Toolbars" and then "Customize..." in the list box which appears.

"FluidEXL Graphics Eng"

is situated at the bottom of the "Toolbars" entries, which must be selected by clicking on it. Delete the entry by clicking "Delete". You will be asked whether you really want to delete the toolbar – click "OK".

Within the next step delete the files

LibHuGas.dll

LibHuGas.chm

in the directory selected for the installation of FluidEXL *Graphics*, in the standard case,

C:\Program Files\FluidEXL_Graphics_Eng

using an appropriate program such as Explorer® or Norton Commander.

In order to remove FluidEXL *Graphics* from Windows and the hard drive, 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/Remove Programs" window that appears select

"FluidEXL Graphics Eng"

by clicking on it and click the "Add/Remove..." button. In the following dialog box, click "Automatic" and then "Next >". Click "Finish" in the "Perform Uninstall" window. Answer the question whether all shared components shall be removed with "Yes to All". Finally, close the "Add/Remove Programs" and "Control Panel" windows.

Now FluidEXL *Graphics* has been removed.

3. Program Documentation

3.1 Documentation of FluidEXL *Graphics* including LibHuGas for Excel®

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	[10]	[11]	[17]
Ne	[10]	-	[18],[19],[24],[25]
N ₂	[10]	[12]	[26]
O ₂	[10]	[13]	[21]
CO	[10]	-	[22]
CO ₂	[10]	[14]	[27]
H ₂ O	[10]	[15]	[6]
SO ₂	[10]	-	[18],[19],[24]

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

cp_hscomp_HuGas

Input values:

h - Specific enthalpy h in kJ/kg
 s - Specific entropy s in kJ/(kg K)
 $\text{type} = 0 \rightarrow$ 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_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 $h(p, t, \text{comp})$ and $s(p, t, \text{comp})$ 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_hscomp_HuGas = $-1 \cdot 10^{100}$

Reference:

Gas	c_p, h, s - ideal part	c_p, h, s - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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

cp_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:

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 $s(p, t, \text{comp})$ 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_pscomp_HuGas = $-1 \cdot 10^{100}$ **Reference:**

Gas	$c_{p,s}$ - ideal part	$c_{p,s}$ - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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

cp_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:

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 $s(p, t, \text{comp})$ 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_tscomp_HuGas = $-1 \cdot 10^{100}$ **Reference:**

Gas	$c_{p,s}$ - ideal part	$c_{p,s}$ - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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	[17]
Ne	[18]
N ₂	[20]
O ₂	[21]
CO	[22]
CO ₂	[23]
H ₂ O	[7]
SO ₂	[18]

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	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

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 : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 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:h_ptcomp_HuGas = $-1 \cdot 10^{100}$ **Reference:**

Gas	h - ideal part	h - real part	ice
Ar	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

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	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

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	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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	[17]
Ne	[18],[19],[24],[25]
N ₂	[26]
O ₂	[21]
CO	[22]
CO ₂	[27]
H ₂ O	[6]
SO ₂	[18],[19],[24]

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

Comments:

- 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 ($\psi_w > \psi_{w,\text{sat}}$, $t < 0.01\text{ °C}$) 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	[10]	[11]	[17]
Ne	[10]	-	[18],[19],[24],[25]
N ₂	[10]	[12]	[26]
O ₂	[10]	[13]	[21]
CO	[10]	-	[22]
CO ₂	[10]	[14]	[27]
H ₂ O	[10]	[15]	[6]
SO ₂	[10]	-	[18],[19],[24]

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

p_hscomp_HuGas

Input values:

h - Specific enthalpy h in kJ/kg
 s - Specific entropy s in kJ/(kg K)
 $\text{type} = 0 \rightarrow$ 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_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 $h(p, t, \text{comp})$ and $s(p, t, \text{comp})$ 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_hscomp_HuGas = $-1 \cdot 10^{100}$

Reference:

Gas	h, s - ideal part	h, s - real part	ice
Ar	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

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	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

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

pdsat_pt_HuGas

Input values:p - Pressure p in bart - 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 °CPressure 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 [8]

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:

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

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:

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

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 [8]

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

Comments:

- 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 ($\psi_w > \psi_{w,\text{sat}}$, $t < 0.01\text{ °C}$) 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	[10]	[11]	[17]	[17]
Ne	[10]	-	[18]	[18],[19],[24],[25]
N ₂	[10]	[12]	[20]	[26]
O ₂	[10]	[13]	[21]	[21]
CO	[10]	-	[22]	[22]
CO ₂	[10]	[14]	[23]	[27]
H ₂ O	[10]	[15]	[7]	[6]
SO ₂	[10]	-	[18]	[18],[19],[24]

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: [16]

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

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 °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 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	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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

Result for incorrect input values:

Region_phcomp_HuGas = 0

Reference:

Gas	<i>h</i> - ideal part	<i>h</i> - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

***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	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

$Region = f(p, t, type, comp(1:8))$
Function Name:

Region_ptcomp_HuGas

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 $type = 0 \rightarrow$ composition as mole fraction
 $type = 1 \rightarrow$ 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	s - ideal part	s - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

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	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

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	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

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: [5]

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

t_hscomp_HuGas

Input values:

h - Specific enthalpy h in kJ/kg
 s - Specific entropy s in kJ/(kg K)
 $\text{type} = 0 \rightarrow$ 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_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 $h(p, t, \text{comp})$ and $s(p, t, \text{comp})$

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_hscomp_HuGas = $-1 \cdot 10^{100}$ **Reference:**

Gas	h, s - ideal part	h, s - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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

tw dew_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, N₂, O₂, CO, CO₂, H₂O, SO₂)

Result:

tw dew_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:

tw dew_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 [8]

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	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

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

`v_hscomp_HuGas`

Input values:

h - Specific enthalpy h in kJ/kg
 s - Specific entropy s in kJ/(kg K)
 $\text{type} = 0 \rightarrow$ 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_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 $h(p, t, \text{comp})$ and $s(p, t, \text{comp})$ 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_hscomp_HuGas` = $-1 \cdot 10^{100}$

Reference:

Gas	v, h, s - ideal part	v, h, s - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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 : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 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 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	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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 : $-70\text{ °C} \leq t \leq 3026.85\text{ °C}$
 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

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

Gas	v - ideal part	v - real part	ice
Ar	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

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

`v_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:

`v_tscomp_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 from $s(p, t, \text{comp})$ and calculation 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 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

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	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

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
 type = 0 → composition as mole fraction
 = 1 → 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 ≤ t ≤ 3026.85 °C
 Pressure p : 0.01 bar ≤ p ≤ 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	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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:

$$\text{Humidity ratio of water } x_w = \frac{\frac{\psi_w}{R_w}}{\frac{\psi_w}{R_w} + \frac{1 - \psi_w}{R_{\text{mix}}}}$$

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 [8]

Mole Fraction of Water of Saturated Gas

$$\psi_{w,sat} = f(p, t, \text{type}, \text{comp}(1:8))$$

Function Name:

Psiwsat_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:

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 [8]

3.2 Documentation of the Fortran Source Code of LibHuGas

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

Name in Fortran:

REAL*8 FUNCTION A_PT_HUGAS (REAL*8 P, REAL*8 T, INTEGER*4 TYPE, REAL*8 COMP)

Input values:

P - Pressure p in bar

T - Temperature t in °C

TYPE - composition:

TYPE=1 for composition as mass fraction ξ

TYPE=0 for composition as mole fraction ψ

COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0

COMP(0) - Dummy

COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

a_pt_HuGas - Thermal diffusivity 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:

- 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_pt_HuGas = -1·10¹⁰⁰

Reference:

Gas	ρ, c_p - ideal part	ρ, c_p - real part	λ
Ar	[10]	[11]	[17]
Ne	[10]	-	[18],[19],[24],[25]
N ₂	[10]	[12]	[26]
O ₂	[10]	[13]	[21]
CO	[10]	-	[22]
CO ₂	[10]	[14]	[27]
H ₂ O	[10]	[15]	[6]
SO ₂	[10]	-	[18],[19],[24]

Specific Isobaric Heat Capacity $c_p = f(h, s, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION CP_HS_HUGAS (REAL*8 H, REAL*8 S, INTEGER*4 TYPE, REAL*8
COMP)
```

Input values:

- H - Enthalpy h in kJ/kg
S - Entropy s in kJ/(kg K)
TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

- cp_hs_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 $h(p, t, \text{type}, \text{comp})$ and $s(p, t, \text{type}, \text{comp})$ and calculation of c_p from $c_p(p, t, \text{type}, \text{comp})$

Calculation:

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

Result for incorrect input values:

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

Reference:

Gas	c_p, h, s - ideal part	c_p, h, s - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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

```
REAL*8 FUNCTION CP_PH_HUGAS (REAL*8 P, REAL*8 H, INTEGER*4 TYPE, REAL*8
COMP)
```

Input values:

P - Pressure p in bar

H - Enthalpy h in kJ/kg

TYPE - composition:

TYPE=1 for composition as mass fraction ξ

TYPE=0 for composition as mole fraction ψ

COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0

COMP(0) - Dummy

COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

cp_ph_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:

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

Calculation:

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

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

Result for incorrect input values:

cp_ph_HuGas = -1·10¹⁰⁰

Reference:

Gas	c_p, h - ideal part	c_p, h - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

Specific Isobaric Heat Capacity $c_p = f(p, s, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION CP_PS_HUGAS (REAL*8 P, REAL*8 S, INTEGER*4 TYPE, REAL*8
COMP)
```

Input values:

P - Pressure p in bar
S - Entropy s in kJ/(kg K)
TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

cp_ps_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 $s(p, t, \text{type}, \text{comp})$ and calculation of c_p from $c_p(p, t, \text{type}, \text{comp})$

Calculation:

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

Result for incorrect input values:

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

Reference:

Gas	$c_{p,s}$ - ideal part	$c_{p,s}$ - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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

```
REAL*8 FUNCTION CP_PT_HUGAS (REAL*8 P, REAL*8 T, INTEGER*4 TYPE, REAL*8
COMP)
```

Input values:

P - Pressure p in bar

T - Temperature t in °C

TYPE - composition:

TYPE=1 for composition as mass fraction ξ

TYPE=0 for composition as mole fraction ψ

COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0

COMP(0) - Dummy

COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

cp_pt_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 higher than 500 °C

Result for incorrect input values:

cp_pt_HuGas = -1·10¹⁰⁰

Reference:

Gas	c_p - ideal part	c_p - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

Specific Isobaric Heat Capacity $c_p = f(t, s, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION CP_T S_HUGAS (REAL*8 T, REAL*8 S, INTEGER*4 TYPE, REAL*8
COMP)
```

Input values:

T - Temperature t in °C
S - Entropy s in kJ/(kg K)
TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

cp_ts_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 $s(p, t, \text{type}, \text{comp})$ and calculation of c_p from $c_p(p, t, \text{type}, \text{comp})$

Calculation:

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

Result for incorrect input values:

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

Reference:

Gas	$c_{p,s}$ - ideal part	$c_{p,s}$ - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

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

```
REAL*8 FUNCTION CV_PT_HUGAS (REAL*8 P, REAL*8 T, INTEGER*4 TYPE, REAL*8
COMP)
```

Input values:

P - Pressure p in bar

T - Temperature t in °C

TYPE - composition:

TYPE=1 for composition as mass fraction ξ

TYPE=0 for composition as mole fraction ψ

COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0

COMP(0) - Dummy

COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

cv_pt_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 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 higher than 500 °C

Result for incorrect input values:

cv_pt_HuGas = -1·10¹⁰⁰

Reference:

Gas	c_v - ideal part	c_v - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]

Dynamic Viscosity $\eta = f(p, t, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION ETA_PT_HUGAS (REAL*8 P, REAL*8 T, INTEGER*4 TYPE, REAL*8
COMP)
```

Input values:

P - Pressure p in bar

T - Temperature t in °C

TYPE - composition:

TYPE=1 for composition as mass fraction ξ

TYPE=0 for composition as mole fraction ψ

COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0

COMP(0) - Dummy

COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

eta_pt_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 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 ($\psi_w > \psi_{w,\text{sat}}$, $t < 0.01$ °C) as saturated humid gas mixture

Result for incorrect input values:

eta_pt_HuGas = -1·10¹⁰⁰

Reference:

Gas	η
Ar	[17]
Ne	[18]
N ₂	[20]
O ₂	[21]
CO	[22]
CO ₂	[23]
H ₂ O	[7]
SO ₂	[18]

Specific Enthalpy $h = f(p,s,type,comp)$
Name in Fortran:

REAL*8 FUNCTION H_PS_HUGAS (REAL*8 P, REAL*8 S, INTEGER*4 TYPE, REAL*8 COMP)

Input values:

- P - Pressure p in bar
 S - Entropy s in kJ/(kg K)
 TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
 COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

h_ps_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 $s(p,t,type,comp)$ and calculation of h from $h(p,t,type,comp)$

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 higher than 500 °C

Result for incorrect input values:

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

Reference:

Gas	h,s - ideal part	h,s - real part	Ice
Ar	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

Specific Enthalpy $h = f(p, t, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION H_PT_HUGAS (REAL*8 P, REAL*8 T, INTEGER*4 TYPE, REAL*8 COMP)
```

Input values:

P - Pressure p in bar
T - Temperature t in °C
TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

h_pt_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:

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 higher than 500 °C

Result for incorrect input values:

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

Reference:

Gas	h - ideal part	h - real part	ice
Ar	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

Specific Enthalpy $h = f(t, s, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION H_TS_HUGAS (REAL*8 T, REAL*8 S, INTEGER*4 TYPE, REAL*8 COMP)
```

Input values:

- T - Temperature t in °C
 S - Entropy s in kJ/(kg K)
 TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
 COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

h_ts_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 $s(p, t, \text{type}, \text{comp})$ and calculation h from $h(p, t, \text{type}, \text{comp})$
 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 higher than 500 °C

Result for incorrect input values:

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

Reference:

Gas	h, s - ideal part	h, s - real part	ice
Ar	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

Isentropic Exponent $\kappa = f(p, t, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION KAPPA_PT_HUGAS (REAL*8 P, REAL*8 T, INTEGER*4 TYPE,
                                REAL*8 COMP)
```

Input values:

P - Pressure p in bar
T - Temperature t in °C
TYPE - composition:
TYPE=1 for composition as mass fraction ξ
TYPE=0 for composition as mole fraction ψ
COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
COMP(0) - Dummy
COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

Kappa_pt_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 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 ($\psi_w > \psi_{w,\text{sat}}$, $t < 0.01$ °C) as saturated humid gas mixture

Result for incorrect input values:

Kappa_pt_HuGas = -1.10¹⁰⁰

Reference:

Gas	v, c_p, c_v - ideal part	v, c_p, c_v - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

Isentropic Exponent $\kappa = f(p,s,type,comp)$
Name in Fortran:

```
REAL*8 FUNCTION KAPPA_PS_HUGAS (REAL*8 P, REAL*8 S, INTEGER*4 TYPE,
                                REAL*8 COMP)
```

Input values:

P - Pressure p in bar
 S - Entropy s in kJ/(kg K)
 TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
 COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

Kappa_ps_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 CO₂ and SO₂ less than saturation pressures

Comments:

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

- 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:

Kappa_ps_HuGas = -1·10¹⁰⁰

Reference:

Gas	v, c_p, c_v, s - ideal part	v, c_p, c_v, s - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

Thermal Conductivity $\lambda = f(p, t, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION LAMBDA_PT_HUGAS (REAL*8 P, REAL*8 T, INTEGER*4 TYPE,
                                REAL*8 COMP)
```

Input values:

P - Pressure p in bar

T - Temperature t in °C

TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ

COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

Lambda_pt_HuGas - Thermal conductivity in W/(m 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:

- 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:

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

Reference:

Gas	λ
Ar	[17]
Ne	[18],[19],[24],[25]
N ₂	[26]
O ₂	[21]
CO	[22]
CO ₂	[27]
H ₂ O	[6]
SO ₂	[18],[19],[24]

Molar mass $M = f(\text{type}, \text{comp})$
Name in Fortran:

REAL*8 FUNCTION M_HUGAS (INTEGER*4 TYPE, REAL*8 COMP)

Input values:

- TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
- COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

M_HuGas - Molar mass in kg/kmol

Result for incorrect input values:

M_HuGas = -1·10¹⁰⁰

Kinematic Viscosity $\nu = f(p, t, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION NY_PT_HUGAS (REAL*8 P, REAL*8 T, INTEGER*4 TYPE, REAL*8 COMP)
```

Input values:

P - Pressure p in bar

T - Temperature t in °C

TYPE - composition:

TYPE=1 for composition as mass fraction ξ

TYPE=0 for composition as mole fraction ψ

COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0

COMP(0) - Dummy

COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

Ny_pt_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_pt_HuGas = -1·10¹⁰⁰

Reference:

Gas	ν - ideal part	ν - real part	λ
Ar	[10]	[11]	[17]
Ne	[10]	-	[18],[19],[24],[25]
N ₂	[10]	[12]	[26]
O ₂	[10]	[13]	[21]
CO	[10]	-	[22]
CO ₂	[10]	[14]	[27]
H ₂ O	[10]	[15]	[6]
SO ₂	[10]	-	[18],[19],[24]

Pressure $p = f(h, s, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION P_HS_HUGAS (REAL*8 H, REAL*8 S, INTEGER*4 TYPE, REAL*8 COMP)
```

Input values:

H - Enthalpy h in kJ/kg

S - Entropy s in kJ/(kg K)

TYPE - composition:

TYPE=1 for composition as mass fraction ξ

TYPE=0 for composition as mole fraction ψ

COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0

COMP(0) - Dummy

COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

p_hs_HuGas - Pressure in bar

Range of validity:

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

Pressure p : 0.01 bar $\leq p \leq$ 16.5·10⁶ bar

Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Iteration of t and p from $h(p, t, \text{type}, \text{comp})$ and $s(p, t, \text{type}, \text{comp})$ 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 higher than 500 °C

Result for incorrect input values:

p_hs_HuGas = -1·10¹⁰⁰

Reference:

Gas	h, s - ideal part	h, s - real part	ice
Ar	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

Pressure $p = f(t, s, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION P_HS_HUGAS (REAL*8 H, REAL*8 S, INTEGER*4 TYPE, REAL*8 COMP)
```

Input values:

T - Temperature t in °C
 S - Entropy s in kJ/(kg K)
 TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
 COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

p_t s_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 CO₂ and SO₂ less than saturation pressures

Comments:

Iteration of p from $s(p, t, \text{type}, \text{comp})$ 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 higher than 500 °C

Result for incorrect input values:

p_hs_HuGas = -1·10¹⁰⁰

Reference:

Gas	s - ideal part	s - real part	ice
Ar	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

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

REAL*8 FUNCTION PDSAT_PT_HUGAS (REAL*8 P, REAL*8 T)

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 = -1·10¹⁰⁰

Reference:

$p_{\text{dsat}}(p, t)$ for $T \geq 273,16$ K from IAPWS-IF97 [1], [2], [3], [4]
 $p_{\text{dsat}}(p, t)$ for $T < 273,16$ K from IAPWS-92 [8]

Relative Humidity $\varphi = f(p, t, \text{type}, \text{comp})$
Name in Fortran:

REAL*8 FUNCTION PHI_PT_HUGAS (REAL*8 P, REAL*8 T, INTEGER*4 TYPE, REAL*8 COMP)

Input values:

P - Pressure p in bar
 T - Temperature t in °C
 TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
 COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

Phi_pt_HuGas - Relative humidity in %

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:

$$\text{Relative humidity } \varphi = \frac{x_w}{\frac{R_1}{R_w} + x_w} \cdot \frac{p}{p_{\text{dsat}}(p, T)} \cdot 100\%$$

with $p_{\text{dsat}}(p, T)$ for $T \geq 273.16\text{ K}$ - Vapour pressure of water in gas mixtures
 for $T < 273.16\text{ K}$ - Sublimation pressures of water in gas mixtures

Result for incorrect input values:

Phi_pt_HuGas = -1·10¹⁰⁰

Reference:

$p_{\text{dsat}}(p, t)$ for $T \geq 273.16\text{ K}$ from IAPWS-IF97 [1], [2], [3], [4]
 $p_{\text{dsat}}(p, t)$ for $T < 273.16\text{ K}$ from IAPWS-92 [8]

Prandtl Number $Pr = f(p, t, \text{type}, \text{comp})$
Name in Fortran:

REAL*8 FUNCTION PR_PT_HUGAS (REAL*8 P, REAL*8 T, INTEGER*4 TYPE, REAL*8 COMP)

Input values:

P - Pressure p in bar

T - Temperature t in °C

TYPE - composition:

TYPE=1 for composition as mass fraction ξ

TYPE=0 for composition as mole fraction ψ

COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0

COMP(0) - Dummy

COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

Pr_pt_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_pt_HuGas = -1.10¹⁰⁰

Reference:

Gas	c_p - ideal part	c_p - real part	η	λ
Ar	[10]	[11]	[17]	[17]
Ne	[10]	-	[18]	[18],[19],[24],[25]
N ₂	[10]	[12]	[20]	[26]
O ₂	[10]	[13]	[21]	[21]
CO	[10]	-	[22]	[22]
CO ₂	[10]	[14]	[23]	[27]
H ₂ O	[10]	[15]	[7]	[6]
SO ₂	[10]	-	[18]	[18],[19],[24]

Gas constant $R = f(\text{type}, \text{comp})$
Name in Fortran:

REAL*8 FUNCTION R_HUGAS (INTEGER*4 TYPE, REAL*8 COMP)

Input values:

TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ

COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

R_HuGas - Gas constant in kJ/(kg K)

Result for incorrect input values:

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

Reference: [16]

Region = f(h,s,type,comp)
Name in Fortran:

```
INTEGER*4 FUNCTION REGION_TS_HUGAS (REAL*8 T, REAL*8 S, INTEGER*4 TYPE,
                                     REAL*8 COMP)
```

Input values:

H - Enthalpy h in kJ/kg
 S - Entropy s in kJ/(kg °C)
 TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
 COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

Region_hs_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 and t from $s(p,t,type,comp)$ and $h(p,t,type,comp)$ and calculation of *Region* from $Region(p,t,type,comp)$

Result for incorrect input values:

Region_hs_HuGas = 0

Reference:

Gas	h, s - ideal part	h, s - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

Region = f($p, h, \text{type}, \text{comp}$)
Name in Fortran:

INTEGER*4 FUNCTION REGION_PH_HUGAS (REAL*8 P, REAL*8 H, INTEGER*4 TYPE,
REAL*8 COMP)

Input values:

P - Pressure p in bar

H - Enthalpy h in kJ/kg

TYPE - composition:

TYPE=1 for composition as mass fraction ξ

TYPE=0 for composition as mole fraction ψ

COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0

COMP(0) - Dummy

COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

Region_ph_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 $h(p, t, \text{type}, \text{comp})$ and calculation of *Region* from $\text{Region}(p, t, \text{type}, \text{comp})$

Result for incorrect input values:

Region_ph_HuGas = 0

Reference:

Gas	h - ideal part	h - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

Region = f(p,s,type,comp)
Name in Fortran:

```
INTEGER*4 FUNCTION REGION_PS_HUGAS (REAL*8 P, REAL*8 S, INTEGER*4 TYPE,
                                     REAL*8 COMP)
```

Input values:

P - Pressure p in bar

S - Entropy s in kJ/(kg K)

TYPE - composition:

TYPE=1 for composition as mass fraction ξ

TYPE=0 for composition as mole fraction ψ

COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0

COMP(0) - Dummy

COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

Region_ps_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 $s(p,t,type,comp)$ and calculation of $Region$ from $Region(p,t,type,comp)$

Result for incorrect input values:

Region_ps_HuGas = 0

Reference:

Gas	s - ideal part	s - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

Region = f(p,t,type,comp)
Name in Fortran:

```
INTEGER*4 FUNCTION REGION_PT_HUGAS (REAL*8 P, REAL*8 T, INTEGER*4 TYPE,
                                     REAL*8 COMP )
```

Input values:

P - Pressure p in bar

T - Temperature t in °C

TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ

COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

Region_pt_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:

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_pt_HuGas = 0

Region = f(*t,s,type,comp*)
Name in Fortran:

 INTEGER*4 FUNCTION REGION_TS_HUGAS (REAL*8 T, REAL*8 S, INTEGER*4 TYPE,
REAL*8 COMP)

Input values:

T - Temperature *t* in °C
 S - Entropy *s* in kJ/(kg K)
 TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
 COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

Region_ts_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,type,comp*) and calculation of *Region* from *Region*(*p,t,type,comp*)

Result for incorrect input values:

Region_ts_HuGas = 0

Reference:

Gas	s - ideal part	s - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

Density $\rho = f(p, t, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION rho_pTcomp_HuGas (p,T,type,comp (REAL*8 P, REAL*8 T, INTEGER*4
                                         Type, REAL*8 COMP))
```

Input values:

P - Pressure p in bar
T - Temperature t in °C
TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

rho_pt_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_pt_HuGas = -1·10¹⁰⁰

Reference:

Gas	ρ - ideal part	ρ - real part	ice
Ar	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

Specific Entropy $s = f(p, h, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION s_phcomp_HuGas (REAL*8 P, REAL*8 H, INTEGER*4 TYPE,
                                REAL*8 COMP)
```

Input values:

P - Pressure p in bar
H - Enthalpy h in kJ/kg
TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

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

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 higher than 500 °C

Result for incorrect input values:

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

Reference:

Gas	h, s - ideal part	h, s - real part	ice
Ar	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

Specific Entropy $s = f(p, t, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION s_pTcomp_HuGas (REAL*8 P, REAL*8 T, INTEGER*4 TYPE,
                                REAL*8 COMP)
```

Input values:

P - Pressure p in bar
 T - Temperature t in °C
 TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
 COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

s_pt_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 higher than 500 °C

Result for incorrect input values:

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

Reference:

Gas	s - ideal part	s - real part	ice
Ar	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

Surface Tension of Water $\sigma_w = f(t, \text{type}, \text{comp})$
Name in Fortran:

REAL*8 FUNCTION sigmaw_T_HuGas (REAL*8 T, INTEGER*4 TYPE, REAL*8 COMP)

Input values:

T - Temperature t in °C
 TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
 COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

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

Reference: [5]

Temperature $t = f(h, s, \text{type}, \text{comp})$
Name in Fortran:

REAL*8 FUNCTION T_hscomp_HuGas (REAL*8 H, REAL*8 S, INTEGER*4 TYPE, REAL*8 COMP)

Input values:

- H - Enthalpy h in kJ/kg
 S - Entropy s in kJ/(kg K)
 TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
 COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

- t_hs_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 $h(p, t, \text{type}, \text{comp})$ and $s(p, t, \text{type}, \text{comp})$

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 higher than 500 °C

Result for incorrect input values:

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

Reference:

Gas	h, s - ideal part	h, s - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

Temperature $t = f(p, h, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION T_phcomp_HuGas (REAL*8 P, REAL*8 H, INTEGER*4 TYPE,
                                REAL*8 COMP)
```

Input values:

P - Pressure p in bar

H - Enthalpy h in kJ/kg

TYPE - composition:

TYPE=1 for composition as mass fraction ξ

TYPE=0 for composition as mole fraction ψ

COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_{10}$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 \dots \psi_{10}$ in kmol/kmol when TYPE=0

COMP(0) - Dummy

COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

t_ph_HuGas - Temperature 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 CO₂ and SO₂ less than saturation pressures

Comments:

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

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 higher than 500 °C

Result for incorrect input values:

t_ph_HuGas = -1·10¹⁰⁰

Reference:

Gas	h - ideal part	h - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

Temperature $t = f(p, s, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION T_pscomp_HuGas (REAL*8 P, REAL*8 S, INTEGER*4 TYPE,
                                REAL*8 COMP)
```

Input values:

P - Pressure p in bar
 S - Entropy s in kJ/(kg K)
 TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
 COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

t_ps_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 $s(p, t, \text{type}, \text{comp})$

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 higher than 500 °C

Result for incorrect input values:

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

Reference:

Gas	h, s - ideal part	h, s - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

Specific Internal Energy $u = f(p, t, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION u_ptcomp_HuGas (REAL*8 P, REAL*8 T, INTEGER*4 TYPE,
                                REAL*8 COMP)
```

Input values:

P - Pressure p in bar
 T - Temperature t in °C
 TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
 COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

u_pt_HuGas - Specific 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 higher than 500 °C

Result for incorrect input values:

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

Reference:

Gas	u - ideal part	u - real part	ice
Ar	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

Specific Volume $v = f(h, s, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION v_hscomp_HuGas (REAL*8 H, REAL*8 S, INTEGER*4 TYPE,
                                REAL*8 COMP)
```

Input values:

H - Enthalpy h in kJ/kg
 S - Entropy s in kJ/(kg K)
 TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
 COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

v_hs_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 CO₂ and SO₂ less than saturation pressures

Comments:

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

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_hs_HuGas = -1·10¹⁰⁰

Reference:

Gas	v, h, s - ideal part	v, h, s - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

Specific Volume $v = f(p, h, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION v_phcomp_HuGas (REAL*8 P, REAL*8 H, INTEGER*4 TYPE,
                                REAL*8 COMP)
```

Input values:

P - Pressure p in bar
H - Enthalpy h in kJ/kg
TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

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

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

Reference:

Gas	v, h - ideal part	v, h - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

Specific Volume $v = f(p, s, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION v_pscomp_HuGas (REAL*8 P, REAL*8 S, INTEGER*4 TYPE, REAL*8
COMP)
```

Input values:

- P - Pressure p in bar
- S - Entropy s in kJ/(kg K)
- TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
- COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

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

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_ps_HuGas = -1·10¹⁰⁰

Reference:

Gas	v, s - ideal part	v, s - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

Specific Volume $v = f(p, t, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION v_pTcomp_HuGas (REAL*8 P, REAL*8 T, INTEGER*4 TYPE,
                                REAL*8 COMP)
```

Input values:

P - Pressure p in bar
T - Temperature t in °C
TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

v_pt_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 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_pt_HuGas = -1.10¹⁰⁰

Reference:

Gas	v - ideal part	v - real part	ice
Ar	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

Specific Volume $v = f(t, s, \text{type}, \text{comp})$
Name in Fortran:

```
REAL*8 FUNCTION v_Tscomp_HuGas (REAL*8 T, REAL*8 S, INTEGER*4 TYPE,
                                REAL*8 COMP)
```

Input values:

T - Temperature t in °C
 S - Entropy s in kJ/(kg K)
 TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
 COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

v_ts_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 CO₂ and SO₂ less than saturation pressures

Comments:

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

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

Result for incorrect input values:

v_ts_HuGas = -1·10¹⁰⁰

Reference:

Gas	v, s ideal part	v, s real part	ice
Ar	[10]	[11]	-
Ne	[10]	-	-
N ₂	[10]	[12]	-
O ₂	[10]	[13]	-
CO	[10]	-	-
CO ₂	[10]	[14]	-
H ₂ O	[10]	[15]	[9]
SO ₂	[10]	-	-

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

REAL*8 FUNCTION w_ptcomp_HuGas (REAL*8 P, REAL*8 T, INTEGER*4 TYPE, REAL*8 COMP)

Input values:

P - Pressure p in bar
 T - Temperature t in °C
 TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
 COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

w_pt_HuGas - 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_pt_HuGas = -1·10¹⁰⁰

Reference:

Gas	v, c_p, c_v - ideal part	v, c_p, c_v - real part
Ar	[10]	[11]
Ne	[10]	-
N ₂	[10]	[12]
O ₂	[10]	[13]
CO	[10]	-
CO ₂	[10]	[14]
H ₂ O	[10]	[15]
SO ₂	[10]	-

Humidity Ratio (Absolute Humidity) $x_w = f(\text{type}, \text{comp})$
Name in Fortran:

REAL*8 FUNCTION xw_comp_HuGas (INTEGER*4 TYPE, REAL*8 COMP)

Input values:

TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ

COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

xw_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:

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

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

```
REAL*8 FUNCTION PSIWL_PT_HUGAS (REAL*8 P, REAL*8 T, INTEGER*4 TYPE,
                                REAL*8 COMP)
```

Input values:

P - Pressure p in bar
T - Temperature t in °C
TYPE - composition:
 TYPE=1 for composition as mass fraction ξ
 TYPE=0 for composition as mole fraction ψ
COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1
 - composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0
 COMP(0) - Dummy
 COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

Psiwl_pt_HuGas - Mole fraction of water in kmol/kmol

Range of validity:

Temperature t : $t_t(p, \text{type}, \text{comp}) \leq t \leq t_s(p, p_d)$
 (t_s – Boiling 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_pt_HuGas = -1.10¹⁰⁰

Reference:

$p_{dsat}(p, t)$ for $T \geq 273.16 \text{ K}$ from IAPWS-IF97 [1], [2], [3], [4]
 $p_{dsat}(p, t)$ for $T < 273.16 \text{ K}$ from IAPWS-92 [8]

Mole Fraction of Water of Saturated Gas $\psi_{w,sat} = f(p, t, \text{type}, \text{comp})$
Name in Fortran:

REAL*8 FUNCTION PSIWSAT_PT_HUGAS (REAL*8 P, REAL*8 T, INTEGER*4 TYPE,
REAL*8 COMP)

Input values:

P - Pressure p in bar

T - Temperature t in °C

TYPE - composition:

TYPE=1 for composition as mass fraction ξ

TYPE=0 for composition as mole fraction ψ

COMP(0:8) - composition as mass fraction $\xi_1 \dots \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 \dots \psi_8$ in kmol/kmol when TYPE=0

COMP(0) - Dummy

COMP(1)...COMP(8) mass or mole fraction of mixture components

Result:

Psiwsat_pt_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 – Boiling temperature of water in gas mixtures)

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

Comments:

Mole fraction of water of saturated gas: $\psi_{wsat} = \frac{p_{dsat}(p, T)}{p}$

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:

Psiwsat_pt_HuGas = -1.10¹⁰⁰

Reference:

$p_{dsat}(p, t)$ for $T \geq 273,16$ K from IAPWS-IF97 [1], [2], [3], [4]

$p_{dsat}(p, t)$ for $T < 273,16$ K from IAPWS-92 [8]

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, -S03rev, -S04, and -S05
- IAPWS Revised Advisory Note No. 3 on Thermodynamic Derivatives (2008)

Library LibIF97_META

- Industrial Formulation IAPWS-IF97 (Revision 2007) for metastable steam

Humid Combustion Gas Mixtures

Library LibHuGas

- Model: Ideal mixture of the real fluids:
 CO_2 - Span, Wagner H_2O - IAPWS-95
 O_2 - Schmidt, Wagner N_2 - Span et al.
 Ar - Tegeler et al.
 and of the ideal gases:
 SO_2 , CO , Ne
 (Scientific Formulation of Bücker et al.)
 Consideration of:
 • Dissociation from VDI 4670
 • Poynting effect

Humid Air

Library LibHuAir

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

Extremely Fast Property Calculations

Spline-Based Table
 Look-up Method (SBTL)

Library LibSBTL_IF97 Library LibSBTL_95 Library LibSBTL_HuAir

For steam, water, humid air, carbon dioxide and other fluids and mixtures according IAPWS Guideline 2015 for Computational Fluid Dynamics (CFD), real-time and non-stationary simulations

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

Ar	NO	He	Propylene
Ne	H_2O	F_2	Propane
N_2	SO_2	NH_3	Iso-Butane
O_2	H_2	Methane	n-Butane
CO	H_2S	Ethane	Benzene
CO_2	OH	Ethylene	Methanol
Air			

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Humid Air

Library ASHRAE LibHuAirProp

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

Consideration of:

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

www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bücker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bücker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

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

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

$\text{C}_2\text{H}_6\text{O}_2$	Ethylene glycol
$\text{C}_3\text{H}_8\text{O}_2$	Propylene glycol
$\text{C}_2\text{H}_5\text{OH}$	Ethanol
CH_3OH	Methanol
$\text{C}_3\text{H}_8\text{O}_3$	Glycerol
K_2CO_3	Potassium carbonate
CaCl_2	Calcium chloride
MgCl_2	Magnesium chloride
NaCl	Sodium chloride
$\text{C}_2\text{H}_3\text{KO}_2$	Potassium acetate
CHKO_2	Potassium formate
LiCl	Lithium chloride
NH_3	Ammonia

Formulation of the International Institute of Refrigeration (IIR 2010)

Ethanol

Library LibC2H5OH

Formulation of
Schroeder et al. (2014)

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 and Oxygen

Libraries LibN2 and LibO2

Formulations of Span et al. (2000)
and Schmidt and Wagner (1985)

Hydrogen

Library LibH2

Formulation of
Leachman et al. (2009)

Helium

Library LibHe

Formulation of
Arp et al. (1998)

Hydrocarbons

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

Isopentane C_5H_{12} **Library LibC5H12_Iso**

Neopentane C_5H_{12} **Library LibC5H12_Neo**

Isohexane C_6H_{14} **Library LibC6H14**

Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

Carbon monoxide **CO** **Library LibCO**

Carbonyl sulfide **COS** **Library LibCOS**

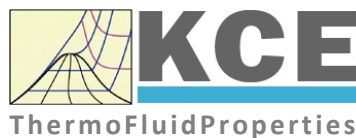
Hydrogen sulfide **H₂S** **Library LibH2S**

Nitrous oxide **N₂O** **Library LibN2O**

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

Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)



For more information please contact:

KCE-ThermoFluidProperties UG & Co. KG
Prof. Dr. Hans-Joachim Kretzschmar
Wallotstr. 3
01307 Dresden, Germany

Internet: www.thermofluidprop.com
Email: info@thermofluidprop.com
Phone: +49-351-27597860
Mobile: +49-172-7914607
Fax: +49-3222-1095810

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
- Thermal diffusivity a

Backward Functions

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

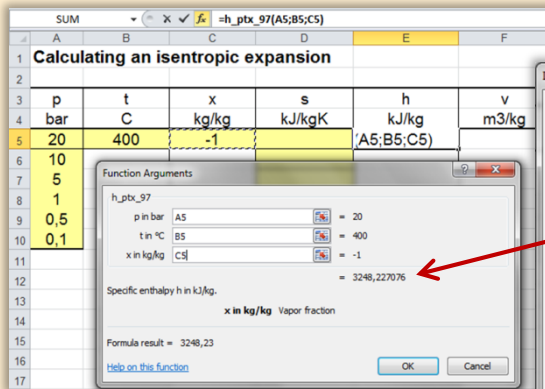
Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

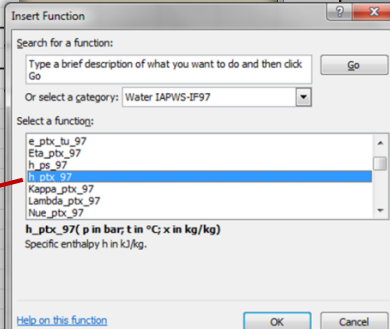
^a Not all of these property functions are available in all property libraries.

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

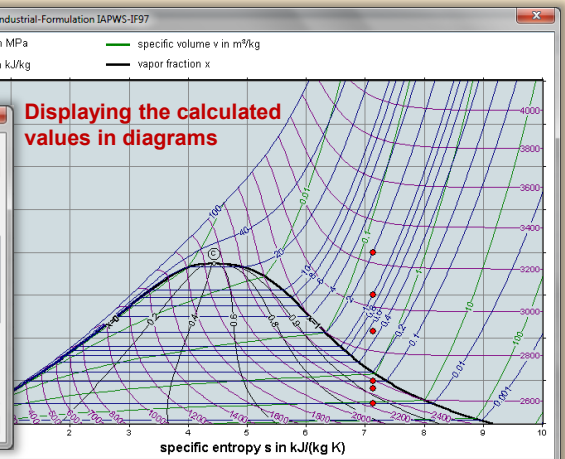
Add-In **FluidEXL** Graphics for Excel®



Choosing a property library and a function



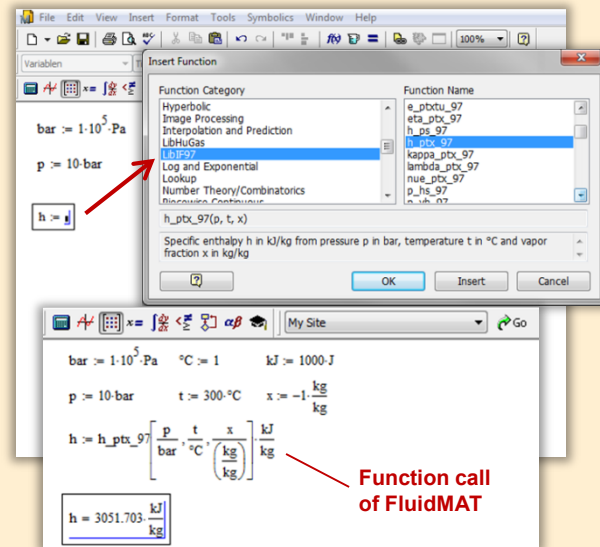
Displaying the calculated values in diagrams



Menu for the input of given property values

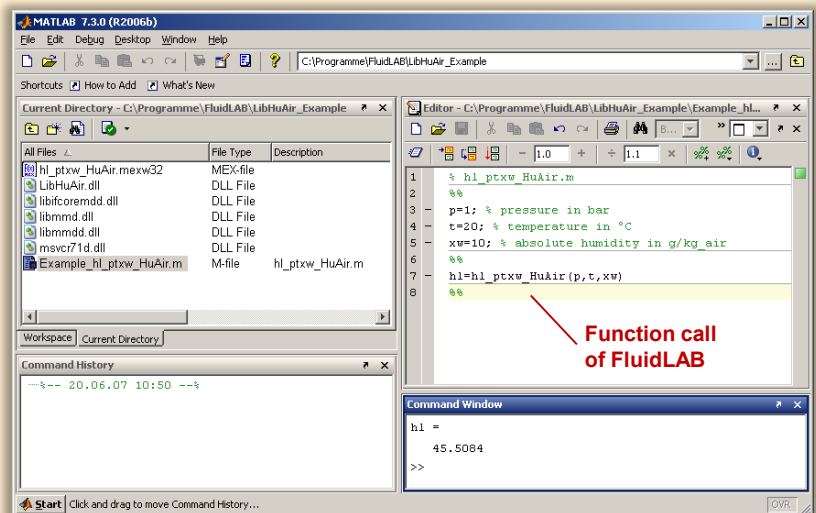
Add-On **FluidMAT** for Mathcad®
Add-On **FluidPRIME** for Mathcad Prime®

The property libraries can be used in Mathcad® and Mathcad Prime®.



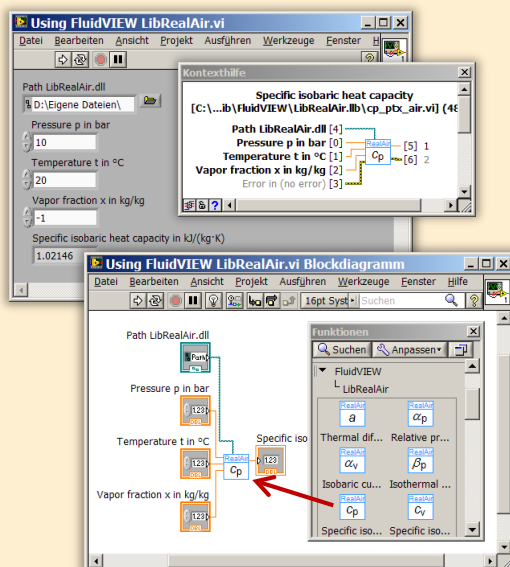
Add-On **FluidLAB** for MATLAB® and SIMULINK®

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



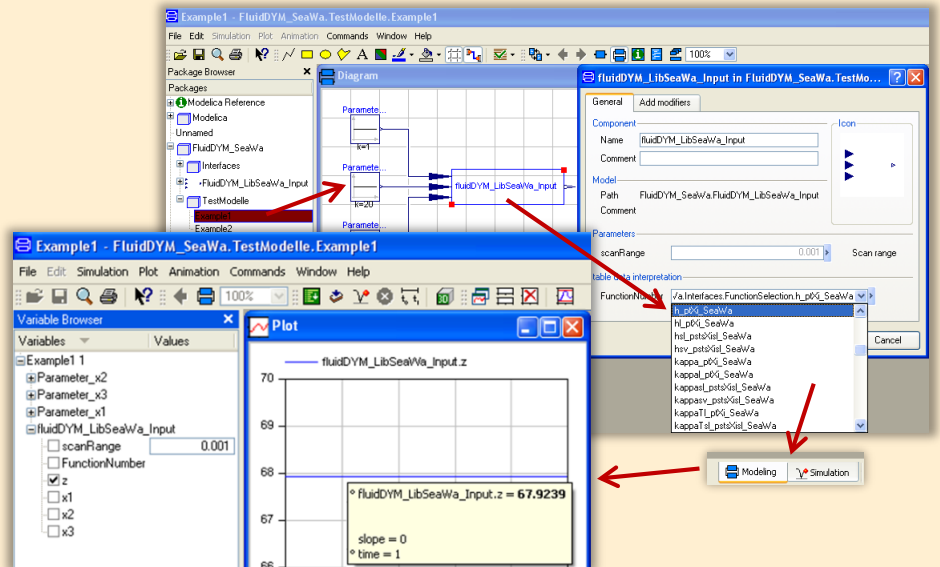
Add-On **FluidVIEW** for LabVIEW™

The property functions can be calculated in LabVIEW™.

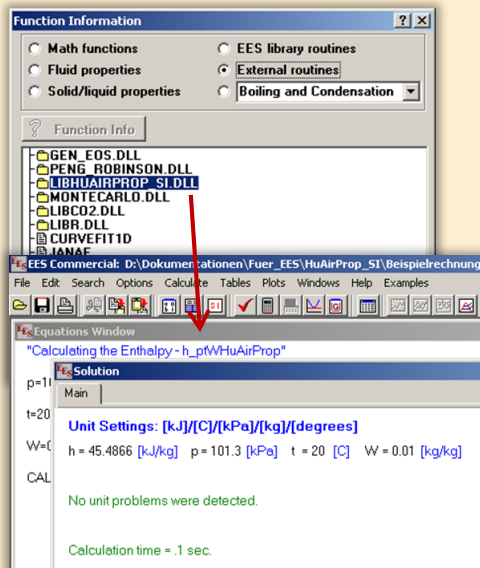


Add-On **FluidDYM** for DYMOLA® (Modelica) and SimulationX®

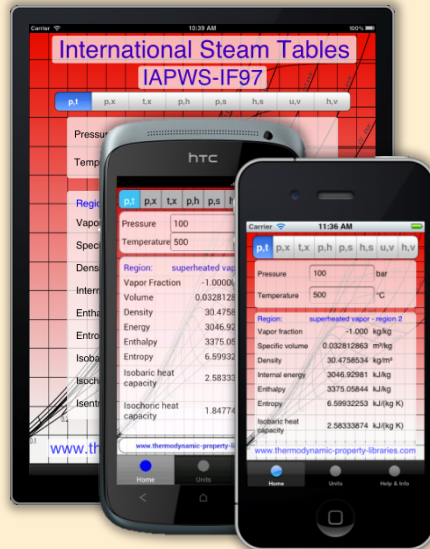
The property functions can be called in DYMOLA® and SimulationX®.



Add-On **FluidEES** for Engineering Equation Solver®



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



Online Property Calculator at www.thermofluidprop.com

Zittau's Fluid Property Calculator

Fluid:

Function:

Unit System:

Enter given values: [Range of validity](#)

Pressure p: bar

Temperature t: °C

Vapor fraction x: kg/kg

Calculate / Recalculate

Result:

Specific enthalpy h = 3097.38 [kJ/kg]

For further information on property libraries available for EXCEL®, MATLAB®, Mathcad®, Engineering Equation Solver®, DYMOLA® (Modelica), SimulationX®, and LabView® click [here](#)

An App for calculating steam properties on iPhone, iPad, and iPod touch can be found [here](#)

PDF with the description

© Zittau/Görlitz University of Applied Sciences
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Dr. Ines Stoecker
Programmer: Joachim Posselt

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www.thermofluidprop.com
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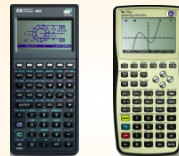
Property Software for Pocket Calculators

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

For more information please contact:



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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
- Thermal diffusivity a

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 used in process modeling can be calculated.

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

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] IAPWS Release on Surface Tension of Ordinary Water Substance 1994.
IAPWS Sekretariat, Dooley, B., EPRI, Palo Alto CA, (1994)
- [6] Release on the IAPS Formulation 1985 for the Thermal Conductivity of Ordinary Water Substance.
IAPWS Sekretariat, Dooley, B., EPRI, Palo Alto CA, (1985)
- [7] Release on the IAPS Formulation 1985 for the Viscosity of Ordinary Water Substance.
IAPWS Sekretariat, Dooley, B., EPRI, Palo Alto CA, (1985)
- [8] Revised Release on Pressure along the Melting and Sublimation Curves of Ordinary Water Substance.
IAPWS Sekretariat, Dooley, B., EPRI, Palo Alto CA (1993)
- [9] Hyland, R. W.; Wexler, A.:
Formulations for the Thermodynamic Properties of Saturated Phases of H₂O from 173.15 K to 473.15 K.
Report No. 2793 (RP-216), National Bureau of Standards, Washington, D.C. (1983)
- [10] Bückner, D.; Span, R.; Wagner, W.:
Thermodynamic Property Models for Moist Air and Combustion Gases.
J. Eng. Gas Turb. Power 125 (2003) 374-383.
- [11] 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.
- [12] 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.

- [13] 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.
- [14] 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.
- [15] Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of
Ordinary Water Substance for General and Scientific Use.
The International Association for the Properties of Water and Steam, Fredericia (1996)
- [16] Verein Deutscher Ingenieure
Thermodynamische Stoffwerte von feuchter Luft und Verbrennungsgasen.
VDI 4670, Entwurf (2000)
- [17] Lemmon, E. W.; Jacobsen, R. T.:
Preliminary equation for viscosity and thermal conductivity of argon.
NIST (2001)
- [18] 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
- [19] 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
- [20] Lemmon, E. W.; Jacobsen, R. T.:
Preliminary equation for viscosity of nitrogen.
NIST (1999)
- [21] Lemmon, E. W.; Jacobsen, R. T.:
Preliminary equation for viscosity and thermal conductivity of oxygen.
NIST (2001)
- [22] National Institute of Standards and Technology
Viscosity and thermal conductivity of carbon monoxide.
Coefficients are taken from NIST14, Version 9.08
- [23] Fenghour, A.; Wakeham, W. A.; Vesovic, V.:
The viscosity of carbon dioxide.
Journal of Physical and Chemical Reference Data 27 (1998) No. 1
- [24] Reid, R. C.; Prausnitz, J. M.; Poling, B. E.:
The Properties of Gases and Liquids.
4th edition, McGraw-Hill Book Company, New York (1987)
- [25] 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)
- [26] Lemmon, E. W.; Jacobsen, R. T.:
Preliminary equation for thermal conductivity of nitrogen.
NIST (1999)

- [27] Vesovic, V.; Wakeham, W. A.; Olchow, 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

Period from 2018 to 2022

The following companies and institutions use the property libraries:

- FluidEXL *Graphics* for Excel® incl. VBA
- FluidLAB for MATLAB® and Simulink
- FluidMAT for Mathcad®
- FluidPRIME for Mathcad Prime®
- FluidEES for Engineering Equation Solver® EES
- FluidDYM for Dymola® (Modelica) and SimulationX®
- FluidVIEW for LabVIEW™
- FluidPYT for Python
- FluidJAVA for Java
- DLLs for Windows Applications
- Shared Objects for Linux
- Shared Objects for macOS.

2022

ASTG, Graz, Austria	12/2022
Wandschneider + Gutjahr, Hamburg	
RWE Supply & Trading, Essen	11/2022
Stadtwerke Rosenheim	
CEA, Saclay, France	10/2022
RWE Supply & Trading, Essen	
SEEC Saudi Energy Efficiency Center, Riyadh, Saudi Arabia	
MAN, Copenhagen, Denmark	
Hermeler & Partner Consulting Engineers, Sassenberg	09/2022
Envi Con, Nürnberg	
Drill Cool Systems, Bakersfield CA, USA	
RWE Supply & Trading, Essen	
Maerz Ofenbau, Zürich, Switzerland	
Saale Energie, Schkopau	
ERGO, Dresden	
Mainova, Frankfurt/Main	
Bundeswehr, Koblenz	08/2022
RWE Supply & Trading, Essen	
Grenzebach Corporation, Newnan GE, USA	
AGRANA, Gmuend, Austria	07/2022
MIBRAG, Zeitz	
Hochschule Niederrhein, Krefeld	
ULT, Löbau	06/2022
LEAG, Cottbus	
VPC Group, Vetschau	

Wärme, Hamburg	
ILK, Dresden	
Stricker IB, Küssnacht a. Rigi, Switzerland	
LEAG, Cottbus	05/2022
RWE Supply & Trading, Essen	
IGT Tomalla, Kreuztal	
B+T Engineering, Dübendorf, Switzerland	
Stricker IB, Küssnacht a. Rigi, Switzerland	
Vogelsang & Benning, Bochum	04/2022
Frischli, Rehburg-Loccum	
BPS Consulting, Sprengel	03/2022
HS Hannover, Maschinenbau & BioVT	
M+M Turbinentechnik, Bad Salzuflen	
Uni. Strathclyde, Glasgow, UK	02/2022
Delta Energy Group, Jiaozhou City, Qingdao, China	
Wetzel IB, Guben	
Wijbenga, PC Geldermalsen, The Netherlands	
Voith Paper, Heidenheim	
HS Zittau/Görlitz, Maschinenwesen	01/2022
Thermische Abfallbehandlung, Lauta	
Webb Institute, Glen Cove NY, USA	
TU Berlin, Umweltverfahrenstechnik	
SachsenEnergie, Dresden	
Doosan, Chang-won-si, Gyeongsangnam-do, South Korea	
KW3, LH Veenendaal, The Netherlands	
Université du Luxembourg, Esch-sur-Alzette	
Enseleit IB, Mansfeld	
Caliqua/Equans, Zürich, Switzerland	
Rudnick & Enners, Alpenrod	

2021

Wenisch IB, Vetschau	12/2021
PPCHEM, Hinwil, Switzerland	
KW3, The Netherlands	
BASF Ludwigshafen	
Air-Consult, Jena	
Sjerp & Jongeneel, RB Zoetermeer, The Netherlands	11/2021
Maerz Ofenbau, Zürich, Switzerland	
RWE Supply & Trading, Essen	
Hahn IB, Dresden	10/2021
Therm, South Africa	
RWE Supply & Trading, Essen	
TH Nürnberg, Verfahrenstechnik	09/2021
RWE Supply & Trading, Essen	
Enseleit IB, Mansfeld	
SachsenEnergie, Dresden	
BSH Hausgeräte, Berlin	

Norsk Energi, Oslo, Norway	08/2021
AKM Industrieanlagen, Haltern	
Drill Cool Systems, Bakersfield CA, USA	
Siemens Energy Global, Erlangen	07/2021
Wulff & Umag, Husum	
Planungsbüro Waidhas, Chemnitz	
Burkhardt Energie Technik, Mühlhausen	
Lücke IB, Paderborn	06/2021
TU Dresden, Energieverfahrenstechnik	
Wärme, Hamburg	
AL-KO Therm, Kötz	
PCK Raffinerie, Schwedt	
Vogelsang & Benning, Bochum	05/2021
MTU, München	
VPC Group, Vetschau	
AVG, Köln	04/2021
TH Ulm, Institut für Fahrzeugtechnik	
Marty IB, Oberwil, Switzerland	
HypTec, Lebring, Austria	
Lopez IB, Getxo, Bizkaia, Spain	03/2021
GM Remediation Systems, Leoben, Austria	
Jager Kältetechnik, Osnabrück	
T&M Automation, GR Leidschendam, The Netherlands	
RWE Supply & Trading, Essen	
Stadtwerke Leipzig	
Beuth Hochschule für Technik, Berlin	
Beleth IB, Woeth	02/2021
ZTL, Thal, Austria	
ETABO Bochum	
RWE Supply & Trading, Essen	
Onyx Germany, Berlin	
TU Dresden, Kältetechnik	
GOHL-KTK, Durmersheim	
Therm Development, South Africa	
thermofin, Heinsdorfergrund	
RWE Supply & Trading, Essen	01/2021
STEAG, Essen	
ETA Energieberatung, Pfaffenhofen	
Enex Power, Kirchseeon	

2020

Drill Cool, Bakersfield CA, USA	12/2020
Manders, The Netherlands	
RWE Supply & Trading, Essen	
NEOWAT Lodz, Poland	
University of Duisburg-Essen, Duisburg	11/2020
Stellenbosch University, South Africa	

University De France-COMTe, France	
RWE, Essen	
STEAG, Herne	
Isenmann Ingenieurbüro	
University of Stuttgart, ITLR, Stuttgart	
Norsk Energi, Oslo, Norway	
TGM Kanis, Nürnberg	
Stadtwerke Neuburg	10/2020
Smurfit Kappa, Roermond, The Netherlands	
RWE, Essen	
Hochschule Zittau/Görlitz, Wirtschaftsingenieurwesen	
Stadtwerke, Neuburg	
ILK, Dresden	
ATESTEO, Alsdorf	
Hochschule Zittau/Görlitz, Maschinenwesen	
TH Nürnberg, Verfahrenstechnik	
Drill Cool, Bakersfield CA,USA	09/2020
RWE, Essen	
2Meyers Ingenieurbüro, Nürnberg	
FELUWA, Mürlenbach	
Stadtwerke Neuburg	
Caverion, Wien, Austria	
GMVA Niederrhein, Oberhausen	
INWAT Lodz, Poland	
Troche Ingenieurbüro, Hayingen	08/2020
CEA Saclay, France	
VPC, Vetschau	07/2020
FSK System-Kälte-Klima, Dortmund	
Exergie Etudes, Sarl, Switzerland	
AWG Wuppertal	
STEAG Energy Services, Zwingenberg	
Hochschule Braunschweig	06/2020
DBI, Leipzig	
GOHL-KTK, Dumersheim	
TU Dresden, Energieverfahrenstechnik	
BASF SE, ESI/EE, Ludwigshafen	
Wärme Hamburg	
Ruchti Ingenieurbüro, Uster, Switzerland	
IWB, Basel, Switzerland	
Midiplan, Bietingen-Bissingen	05/2020
Knieschke, Ingenieurbüro	
RWE, Essen	
Leser, Hamburg	
AGRANA, Gmünd, Austria	
EWT Wassertechnik, Celle	
Hochschule Darmstadt	04/2020
MTU München CCP	
HAW Hamburg	03/2020

Hanon, Novi Jicin, Czech Republic	
TU Dresden, Kältetechnik	
MAN, Copenhagen, Denmark	
EnerTech, Radebeul	02/2020
LEAG, Cottbus	
B+B Engineering Magdeburg	
Hochschule Offenburg	
WIB, Dennheritz	01/2020
Universität Duisburg-Essen, Strömungsmaschinen	
Kältetechnik Dresden-Bremen	
TH Ingolstadt	
Vattenfall AB, Jokkmokk, Sweden	
Fraunhofer UMSICHT	

2019

PEU Leipzig, Rötha	12/2019
MB-Holding, Vestenbergsgreuth	
RWE, Essen	
Georg-Büchner-Hochschule, Darmstadt	11/2019
EEB ENERKO, Aldenhoven	
Robert Benoufa Energietechnik, Wiesloch	
Kehrein & Kubanek Klimatechnik, Moers	10/2019
Hanon Systems Autopal Services, Hluk, Czech Republic	
CEA Saclay, Gif Sur Yvette cedex, France	
Saudi Energy Efficiency Center SEEC, Riyadh, Saudi Arabia	
VPC, Vetschau	09/2019
jGanser PM + Engineering, Forchheim	
Endress+Hauser Flowtec AG, Reinach, Switzerland	
Ruchti IB, Uster, Switzerland	
ZWILAG Zwischenlager Würenlingen, Switzerland	08/2019
Hochschule Zittau/Görlitz, Faculty Maschinenwesen	
Stadtwerke Neubrandenburg	
Physikalisch Technische Bundesanstalt PTB, Braunschweig	
GMVA Oberhausen	07/2019
Endress+Hauser Flowtec AG, Reinach, Switzerland	
WARNICA, Waterloo, Canada	
MIBRAG, Zeitz	06/2019
Pöyry, Zürich, Switzerland	
RWTH Aachen, Institut für Strahlantriebe und Turbomaschinen	
Midiplan, Bietigheim-Bissingen	
GKS Schweinfurt	
HS Zittau/Görlitz, Wirtschaftswissenschaften und Wirtschaftsingenieurwesen	
ILK Dresden	
HZDR Helmholtz Zentrum Dresden-Rossendorf	
TH Köln, Technische Gebäudeausrüstung	05/2019
IB Knittel, Braunschweig	
Norsk Energi, Oslo, Norway	

STEAG, Essen	
Stora Enso, Eilenburg	
IB Lücke, Paderborn	
Haarslev, Sonderso, Denmark	
MAN Augsburg	
Wieland Werke, Ulm	04/2019
Fels-Werke, Elbingerode	
Univ. Luxembourg, Luxembourg	
BTU Cottbus, Power Engineering	03/2009
Eins-Energie Sachsen, Schwarzenberg	
TU Dresden, Kälte- und Kryotechnik	
ITER, St. Paul Lez Durance Cedex, France	
Fraunhofer UMSICHT, Oberhausen	
Comparex Leipzig for Spedition Thiele HEMMERSBACH	
Rückert NaturGas, Lauf/Pegnitz	
BASF, Basel, Switzerland	02/2019
Stadtwerke Leipzig	
Maerz Ofenbau Zürich, Switzerland	
Hanon Systems Germany, Kerpen	
Thermofin, Heinsdorfergrund	01/2019
BSH Berlin	

2018

Jaguar Energy, Guatemala	12/2018
WEBASTO, Gilching	
Smurfit Kappa, Oosterhout, Netherlands	
Univ. BW München	
RAIV, Liberec for VALEO, Prague, Czech Republic	11/2018
VPC Group Vetschau	
SEITZ, Wetzikon, Switzerland	
MVV, Mannheim	10/2018
IB Troche	
KANIS Turbinen, Nürnberg	
TH Ingolstadt, Institut für neue Energiesysteme	
IB Kristl & Seibt, Graz, Austria	09/2018
INEOS, Köln	
IB Lücke, Paderborn	
Südzucker, Ochsenfurt	08/2018
K&K Turbinenservice, Bielefeld	07/2018
OTH Regensburg, Elektrotechnik	
Comparex Leipzig for LEAG, Berlin	06/2018
Münstermann, Telgte	05/2018
TH Nürnberg, Verfahrenstechnik	
Universität Madrid, Madrid, Spanien	
HS Zittau/Görlitz, Wirtschaftsingenieurwesen	
HS Niederrhein, Krefeld	
Wilhelm-Büchner HS, Pfungstadt	03/2018

GRS, Köln	
WIB, Dennheritz	
RONAL AG, Härklingen, Schweiz	02/2018
Ingenieurbüro Leipert, Riegelsberg	
AIXPROCESS, Aachen	
KRONES, Neutraubling	
Doosan Lentjes, Ratingen	01/2018