Hochschule
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UNIVERSITY OF APPLIED SCIENCES

Faculty of
MECHANICAL ENGINEERING
Department of
TECHNICAL THERMODYNAMICS

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

LibHuGas

FluidEXL^{Graphics}

Contents

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0. Package Contents

0.1 Zip files for 32-bit Office®

The following zip files are delivered for your computer running a 32-bit Office® version.

English zip file "CD_FluidEXL_Graphics_LibHuGas_Eng.zip" including the following files:

FluidEXL_Graphics_Eng_Setup.exe	- English installation program for the Add-In FluidEXL$^{\mathit{Graphics}}$ for use in Excel®
FluidEXL_Graphics_Eng.xla	- English Add-In for FluidEXL$^{\mathit{Graphics}}$
LibHuGas.dll	- Dynamic link library for use in Windows® programs
LibHuGas.hlp	- Help file for the LibHuGas property library
FluidEXL_Graphics_LibHuGas_Docu_Eng.pdf	- User’s Guide

German zip file "CD_FluidEXL_Graphics_LibHuGas.zip" including the following files:

FluidEXL_Graphics_Setup.exe	- German installation program for the Add-In FluidEXL$^{\mathit{Graphics}}$ for use in Excel®
FluidEXL_Graphics.xla	- German Add-In for FluidEXL$^{\mathit{Graphics}}$
LibHuGas.dll	- Dynamic link library for use in Windows® programs
LibHuGas.hlp	- Help file for the LibHuGas property library
FluidEXL_Graphics_LibHuGas_Docu_Eng.pdf	- User’s Guide

0.2 Zip files for 64-bit Office®

The following zip files are delivered for your computer running a 64-bit Office® version.

English zip file "CD_FluidEXL_Graphics_LibHuGas_x64_Eng.zip" including the following files and folders:

Files:

FluidEXL_Graphics_LibHuGas_Docu_Eng.pdf	- User’s Guide
FluidEXL_Graphics_Eng.xla	- FluidEXL$^{\mathit{Graphics}}$ Add-In
FluidEXL_Graphics_Eng_64_Setup.msi	- Self-extracting and self-installing program
LibHuGas.dll	- Dynamic link library for use in Windows® programs

LibHuGas.hlp	- Help file for the LibHuGas property library
Setup.exe	- Self-extracting and self-installing program for FluidEXL$^{\mathit{Graphics}}$

Folders:

vcredist_x64	- Folder containing the "Microsoft Visual C++ 2010 x64 Redistributable Pack"
WindowsInstaller3_1	- Folder containing the "Microsoft Windows Installer"

German zip file "CD_FluidEXL_Graphics_LibHuGas_x64.zip" including the following files and folders:

Files:

FluidEXL_Graphics_LibHuGas_Docu_Eng.pdf	- User’s Guide
FluidEXL_Graphics.xla	- FluidEXL$^{\mathit{Graphics}}$ Add-In
FluidEXL_Graphics_64_Setup.msi	- Self-extracting and self-installing program
LibHuGas.dll	- Dynamic link library for use in Windows® programs
LibHuGas.hlp	- Help file for the LibHuGas property library
Setup.exe	- Self-extracting and self-installing program for FluidEXL$^{\mathit{Graphics}}$

Folders:

vcredist_x64	- Folder containing the "Microsoft Visual C++ 2010 x64 Redistributable Pack"
WindowsInstaller3_1	- Folder containing the "Microsoft Windows Installer"

1. Property Functions

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

Function	Function Name	Call of Fortran Program	Property or Function	Unit
$\kappa = \mathrm{f}(p,t)$	Kappa_ptcomp_HuGas	= kappa_pTcomp_HuGas(p,T,type,comp)	Isentropic exponent	-
$\lambda = \mathrm{f}(p,t)$	Lambda_ptcomp_HuGas	= lambda_pTcomp_HuGas(p,T,type,comp)	Thermal conductivity	$\mathrm{W/(m \cdot K)}$
M	M_comp_HuGas	= M_comp_HuGas(type,comp)	Molar mass	kg/kmol
$\nu = \mathrm{f}(p,t)$	Ny_ptcomp_HuGas	= ny_pTcomp_HuGas(p,T,type,comp)	Kinematic viscosity	$\mathrm{m^2/s}$
$p = \mathrm{f}(h,s)$	p_hscomp_HuGas	= p_hscomp_HuGas(h,s,type,comp)	Backward function: Pressure from enthalpy and entropy	bar
$p = \mathrm{f}(t,s)$	p_tscomp_HuGas	= p_Tscomp_HuGas(T,s,type,comp)	Backward function: Pressure from temperature and entropy	bar
$p_{\mathrm{dsat}} = \mathrm{f}(p,t)$	pdsat_pt_HuGas	= pdsat_pT_HuGas(p,T)	Saturation pressure of water in mixture	bar
$\varphi = \mathrm{f}(p,t)$	Phi_ptcomp_HuGas	= phi_pTcomp_HuGas(p,T,type,comp)	Relative humidity	%
$\mathrm{Pr} = \mathrm{f}(p,t)$	Pr_ptcomp_HuGas	= Pr_pTcomp_HuGas(p,T,type,comp)	Prandtl number	-
$\psi_{\mathrm{wl}} = \mathrm{f}(p,t)$	Psiwl_ptcomp_HuGas	= psiwl_pTcomp_HuGas(p,T,type,comp)	Mole fraction of water (liquid)	kmol/kmol
$\psi_{\mathrm{wsat}} = \mathrm{f}(p,t)$	Psiwsat_ptcomp_HuGas	= psiwsat_pTcomp_HuGas(p,T,type,comp)	Mole fraction of water of the saturated gas	kmol/kmol
R	R_comp_HuGas	= R_comp_HuGas(type,comp)	Gas constant	$\mathrm{kJ/(kg \cdot K)}$
Region = 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	-
$\rho = \mathrm{f}(p,t)$	Rho_ptcomp_HuGas	= rho_pTcomp_HuGas(p,T,type,comp)	Density	kg/m^3
$s = \mathrm{f}(p,h)$	s_phcomp_HuGas	= s_phcomp_HuGas(p,h,type,comp)	Backward function: Specific entropy from pressure and specific enthalpy	kJ/(kg·K)
$s = \mathrm{f}(p,t)$	s_ptcomp_HuGas	= s_pTcomp_HuGas(p,T,type,comp)	Entropy	kJ/(kg·K)
$\sigma_\mathrm{w} = \mathrm{f}(t)$	Sigmaw_t_HuGas	= sigmaw_T_HuGas(T)	Surface tension of water	N/m
$t = \mathrm{f}(h,s)$	t_hscomp_HuGas	= T_hscomp_HuGas(h,s,type,comp)	Backward function: Temperature from enthalpy and entropy	°C
$t = \mathrm{f}(p,h)$	t_phcomp_HuGas	= T_phcomp_HuGas(p,h,type,comp)	Backward function: Temperature from pressure and enthalpy	°C
$t = \mathrm{f}(p,s)$	t_pscomp_HuGas	= T_pscomp_HuGas(p,s,type,comp)	Backward function: Temperature from pressure and entropy	°C
$t_\mathrm{w,dew} = \mathrm{f}(p)$	twdew_pcomp_HuGas	= Twdew_pcomp_HuGas(p,type,comp)	Dew point temperature of water	°C
$u = \mathrm{f}(p,t)$	u_ptcomp_HuGas	= u_pTcomp_HuGas(p,T,type,comp)	Specific internal energy	kJ/kg
$v = \mathrm{f}(h,s)$	v_hscomp_HuGas	= v_hscomp_HuGas(h,s,type,comp)	Backward function: Specific volume from enthalpy and entropy	m^3/kg

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

Parameter

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

Parameter for using Fortran Functions of LibHuGas

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

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

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

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

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

In order to know what composition is stored, it can be called by

using get_comp_mass_HuGas or get_comp_mol_HuGas.

Range of Validity

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

Mixture Components

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

Values of the Region Functions

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

Reference States of LibHuGas

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

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

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

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

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

Conversion to the Reference States of the Publications

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

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

2. Application of FluidEXL$^{\mathit{Graphics}}$ in Excel$^{\circledR}$

The FluidEXL$^{\mathit{Graphics}}$ Add-In has been developed to calculate thermodynamic properties in Excel$^{\circledR}$ more conveniently. Within Excel$^{\circledR}$, it enables the direct call of functions relating to humid gas from the LibHuGas property library. Furthermore, the program enables representation of the calculated values in various thermodynamic diagrams.

2.1 Installing FluidEXL$^{\mathit{Graphics}}$

If FluidEXL$^{\mathit{Graphics}}$ has not yet been installed or if there is a version installed which has been delivered before June 2010, please complete the initial installation procedure described below.

If FluidEXL$^{\mathit{Graphics}}$ has already been installed in a version which has been delivered after June 2010, you simply need to copy the files which belong to the LibHuGas library. In this case, follow the subsection "Adding the LibHuGas Library" on page 2/11.

Installing FluidEXL$^{\mathit{Graphics}}$ for 32-bit Office$^{\circledR}$

In this section, the installation of FluidEXL$^{\mathit{Graphics}}$ for a 32-bit Office$^{\circledR}$ version is described. Before you begin, it is best to uninstall any trial version or full version of FluidEXL$^{\mathit{Graphics}}$ delivered before June 2010.

After you have downloaded and extracted the zip-file

"CD_FluidEXL_Graphics_LibHuGas_Eng.zip"	(for English version of Windows)
"CD_FluidEXL_Graphics_LibHuGas.zip"	(for German version of Windows)

you will see the folder

CD_FluidEXL_Graphics_LibHuGas_Eng	(for English version of Windows)
CD_FluidEXL_Graphics_LibHuGas	(for German version of Windows)

in your Windows Explorer, Norton Commander etc.

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

Within this folder you will see the following files:

FluidEXL_Graphics_LibHuGas_Docu_Eng.pdf	
FluidEXL_Graphics_Eng_Setup.exe	(for English version of Windows)
FluidEXL_Graphics_Setup.exe	(for German version of Windows)
FluidEXL_Graphics_Eng.xla	(for English version of Windows)
FluidEXL_Graphics.xla	(for German version of Windows)
LibHuGas.dll	
LibHuGas.hlp.	

In order to run the installation of FluidEXL$^{\mathit{Graphics}}$ double-click the file

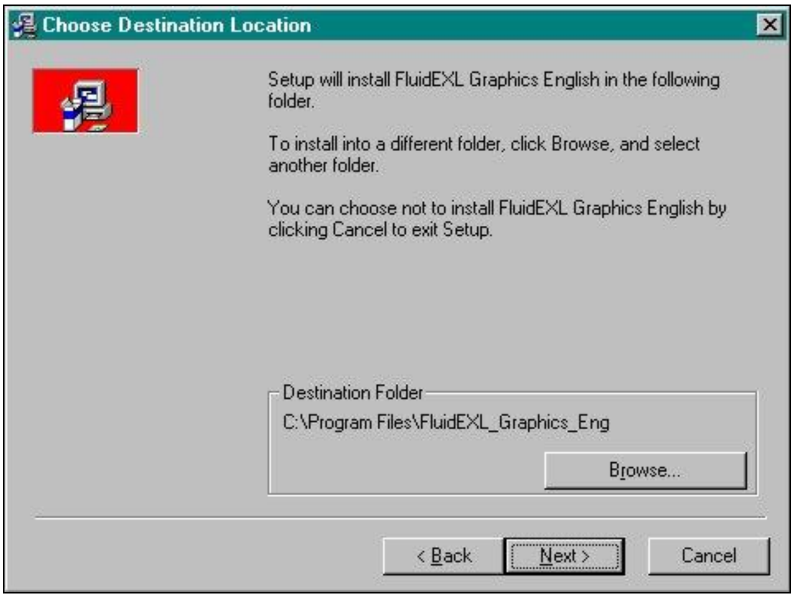
FluidEXL_Graphics_Eng_Setup.exe	(for English version of Windows)
FluidEXL_Graphics_Setup.exe	(for German version of Windows).

Installation may start with a window noting that all Windows programs should be closed. When this is the case, the installation can be continued. Click the "Next >" button.

In the following dialog box, "Choose Destination Location" the standard path offered automatically for the installation of FluidEXL^{Graphics} is

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows).

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



Setup will install FluidEXL Graphics English in the following folder.

To install into a different folder, click Browse, and select another folder.

You can choose not to install FluidEXL Graphics English by clicking Cancel to exit Setup.

Destination Folder
C:\Program Files\FluidEXL_Graphics_Eng

Figure 2.1: Choose Destination Location

Finally, click on "Next >" to continue installation; click "Next >" again in the "Start Installation" window which follows in order to start the installation of FluidEXL^{Graphics}.

After FluidEXL^{Graphics} has been installed, you will see the sentence

"FluidEXL Graphics English has been successfully installed."
"FluidEXL Graphics wurde erfolgreich installiert."

Confirm this by clicking the "Finish" button.

The installation of FluidEXL^{Graphics} has been completed.

During the installation process the following files

Advapi32.dll
DFORMD.dll
Dforrt.dll
UNWISE.EXE
UNWISE.INI
LC.dll
Msvcp60.dll
Msvcrt.dll
INSTALL_EXL.LOG
FluidEXL_Graphics_Eng.xla (for English version of Windows)
FluidEXL_Graphics.xla (for German version of Windows)

have been copied into the chosen destination folder, in the standard case

In addition, the two subdirectories \Formulation97 and \FLuft have been compiled in the destination folder.

In the next step, the following files from the extracted folder

CD_FluidEXL_Graphics_LibHuGas_Eng (for English version of Windows)
CD_FluidEXL_Graphics_LibHuGas (for German version of Windows)

must be copied into the chosen destination folder (the standard being

C:\Program Files\FluidEXL_Graphics_Eng	(for English version of Windows)
C:\Programme\FluidEXL_Graphics	(for German version of Windows)

using an appropriate program such as Explorer or Norton Commander:

FluidEXL_Graphics_Eng.xla	(for English version of Windows)
FluidEXL_Graphics.xla	(for German version of Windows)
LibHuGas.dll	
LibHuGas.hlp.	

Installing FluidEXL^{Graphics} for 64-bit Office®

In this section, the installation of FluidEXL^{Graphics} for a 64-bit Office® version is described. Before you begin, it is best to uninstall any trial version or full version of FluidEXL^{Graphics} delivered before June 2010.

After you have downloaded and extracted the zip-file

"CD_FluidEXL_Graphics_LibHuGas_x64_Eng.zip"	(for English version of Windows)
"CD_FluidEXL_Graphics_LibHuGas_x64.zip"	(for German version of Windows)

you will see the folder

CD_FluidEXL_Graphics_LibHuGas_Eng	(for English version of Windows)
CD_FluidEXL_Graphics_LibHuGas	(for German version of Windows)

in your Windows Explorer, Norton Commander etc.

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

Within this folder you will see the following files

FluidEXL_Graphics_LibHuGas_Docu_Eng.pdf	
FluidEXL_Graphics_Eng.xla	(for English version of Windows)
FluidEXL_Graphics.xla	(for German version of Windows)
FluidEXL_Graphics_Eng_Setup_64.msi	(for English version of Windows)
FluidEXL_Graphics_Setup_64.msi	(for German version of Windows)
LibHuGas.dll	
LibHuGas.hlp	
Setup.exe	

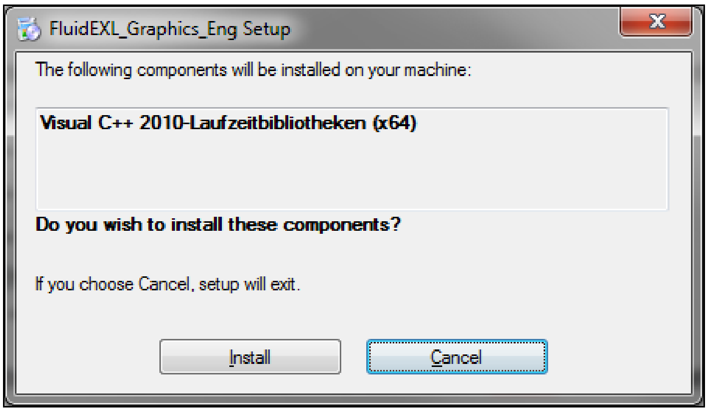
and the folders

vcredist_x64
WindowsInstaller3_1.

In order to run the installation of FluidEXL^{Graphics} double-click the file

Setup.exe.

If the "Microsoft Visual C++ 2010 x64 Redistributable Pack" is not running on your computer yet, installation will start with a window noting that the "Visual C++ 2010 runtime library (x64)" will be installed on your machine (see Figure 2.2).



FluidEXL_Graphics_Eng Setup

The following components will be installed on your machine:

Visual C++ 2010-Laufzeitbibliotheken (x64)

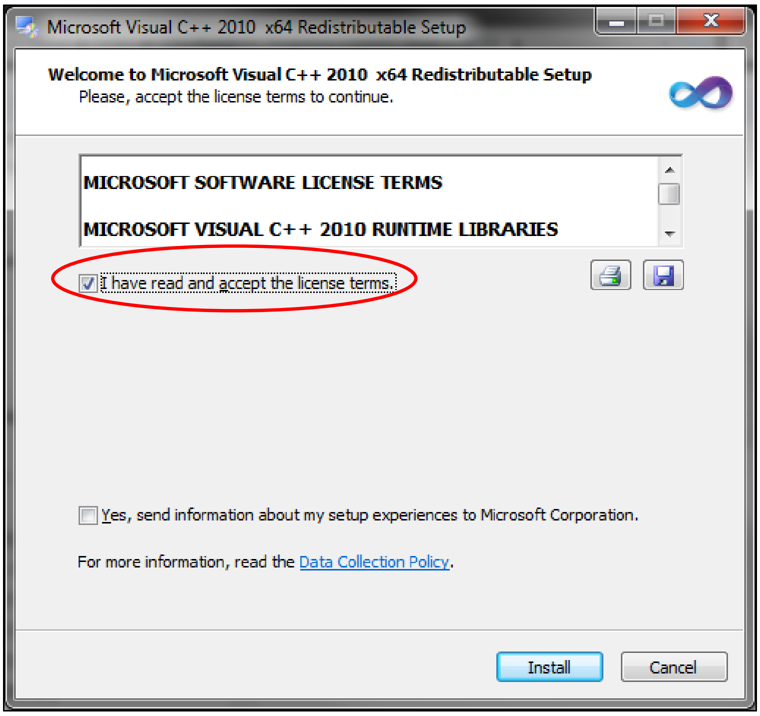
Do you wish to install these components?

If you choose Cancel, setup will exit.

Figure 2.2: Installing the "Visual C++ 2010 runtime library (x64)"

Click on "Install" to continue.

In the following window you are required to accept the Microsoft® license terms to install the "Microsoft Visual C++ 2010 x64 Redistributable Pack" by ticking the box next to "I have read and accept the license terms" (see Figure 2.3).



Microsoft Visual C++ 2010 x64 Redistributable Setup

Welcome to Microsoft Visual C++ 2010 x64 Redistributable Setup

Please, accept the license terms to continue.

MICROSOFT SOFTWARE LICENSE TERMS

MICROSOFT VISUAL C++ 2010 RUNTIME LIBRARIES

☑ I have read and accept the license terms.

☐ Yes, send information about my setup experiences to Microsoft Corporation.

For more information, read the Data Collection Policy.

Figure 2.3: Accepting the license terms

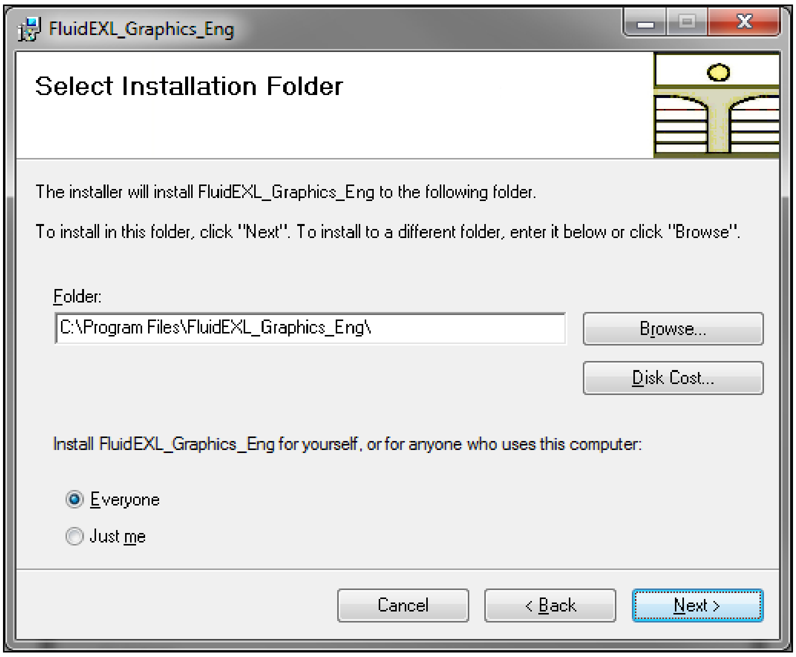
Now click on "Install" to continue installation.

After the "Microsoft Visual C++ 2010 x64 Redistributable Pack" has been installed, you will see the sentence "Microsoft Visual C++ 2010 x64 Redistributable has been installed." Confirm this by clicking "Finish."

Now the installation of FluidEXL$^{\textit{Graphics}}$ starts with a window noting that the installer will guide you through the installation. Click the "Next >" button to continue.

In the following dialog box, "Select Installation Folder," the default path offered automatically for the installation of FluidEXL$^{\textit{Graphics}}$ is

C:\Program Files\FluidEXL_Graphics_Eng	(for English version of Windows)
C:\Programme\FluidEXL_Graphics	(for German version of Windows).



Select Installation Folder

The installer will install FluidEXL_Graphics_Eng to the following folder.

To install in this folder, click "Next". To install to a different folder, enter it below or click "Browse".

Folder:
C:\Program Files\FluidEXL_Graphics_Eng\

Install FluidEXL_Graphics_Eng for yourself, or for anyone who uses this computer:

● Everyone
○ Just me

Figure 2.4: Choosing the Installation Folder of FluidEXL$^{\mathit{Graphics}}$

Finally, click on "Next >" to continue installation; click "Next >" again in the "Confirm Installation" window which follows in order to start the installation of FluidEXL$^{\mathit{Graphics}}$.

After FluidEXL$^{\mathit{Graphics}}$ has been installed, you will see the sentence

> "FluidEXL Graphics English has been successfully installed."
> "FluidEXL Graphics wurde erfolgreich installiert."

Confirm this by clicking the "Close" button.

During the installation process the following files

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

will have been copied into the destination folder chosen, the standard being

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows).

In addition, the two subdirectories \FORMULATION97 and \FLuft were created in the destination folder.

In the next step, the following files

FluidEXL_Graphics_Eng.xla (for English version of Windows)
FluidEXL_Graphics.xla (for German version of Windows)
LibHuGas.dll
LibHuGas.hlp,

which can be found in your CD folder must be copied into the chosen destination folder (the standard being

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows))

using an appropriate program such as Explorer or Norton Commander.

2.2 Registering FluidEXL^{Graphics} as Add-In in Excel®

Registering FluidEXL^{Graphics} as Add-In in Excel®, versions 2003 or earlier

After the installation of FluidEXL^{Graphics}, the program must be registered as an Add-In in Excel®. In order to do so, start Excel and carry out the following steps:

- Click "Tools" in the upper Menu bar in Excel
- Here, click the "Add-Ins..." menu item

After a short delay, the dialog box "Add-Ins" will appear

- Click "Browse..."
- In the following dialog box, click your chosen destination folder (the standard being

C:\Program Files\FluidEXL_Graphics_Eng	(for English version of Windows)
C:\Programme\FluidEXL_Graphics	(for German version of Windows))

- Here click the file

"FluidEXL_Graphics_Eng.xla"	(for English version of Windows) or
"FluidEXL_Graphics.xla"	(for German version of Windows)

and afterwards click "OK".

Now, the entry

"FluidEXL Graphics Eng"	(for English version of Windows)
"FluidEXL Graphics"	(for German version of Windows)

occurs in the Add-Ins list.

Note:

As long as the check box next to the file name

"FluidEXL Graphics Eng"	*(for English version of Windows) or*
"FluidEXL Graphics"	*(for German version of Windows),*

is ticked, this Add-In will be loaded automatically every time you start Excel until you untick the box by clicking on it again.

- In order to register FluidEXL^{Graphics} as an Add-In click "OK" in the "Add-Ins" dialog box.

Now, the new FluidEXL^{Graphics} menu bar will appear in the upper menu area of your Excel screen, marked with a red circle in the next figure.

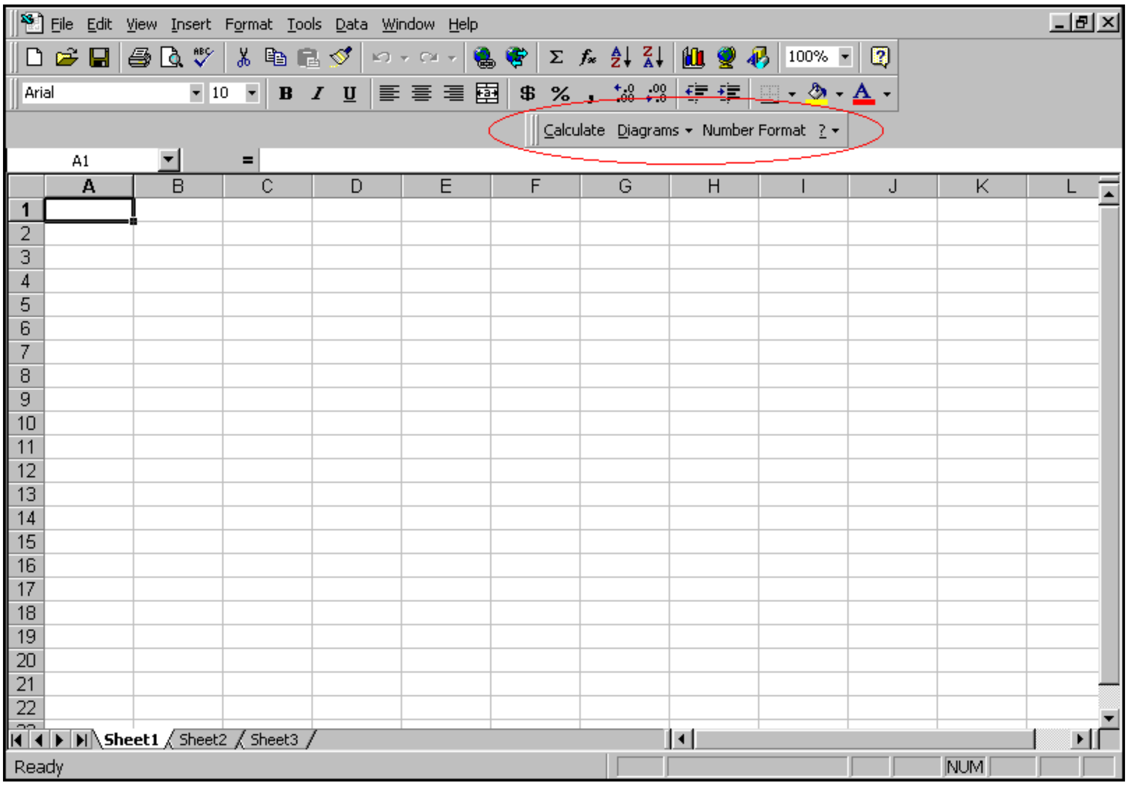


Figure 2.5: Menu bar of FluidEXL*Graphics*

From within Excel you can now select the "Humid Gas LibHuGas" DLL library property functions via the FluidEXL*Graphics* menu bar (the example calculation can be found in chapter 2.5 on page 2/19).

Registering FluidEXL*Graphics* as Add-In in Excel® 2007 (or later versions)

After installation in Windows®, FluidEXL*Graphics* must be registered in Excel® as from version 2007 as an Add-In. For this, start Excel and carry out the following steps:

- Click the Windows Office button in the upper left corner of Excel
- Click on the "Excel Options" button in the menu which pops up (see figure below)

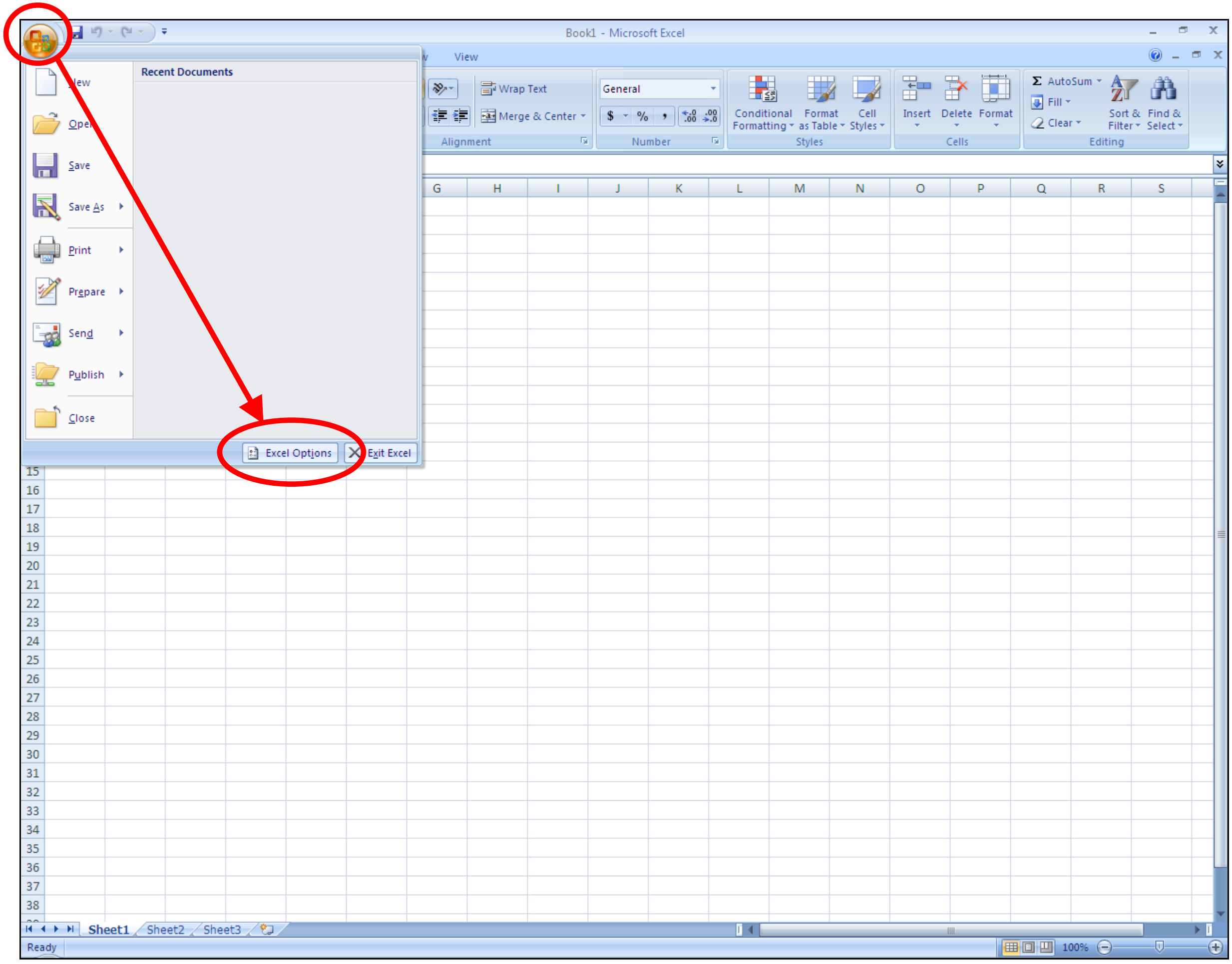
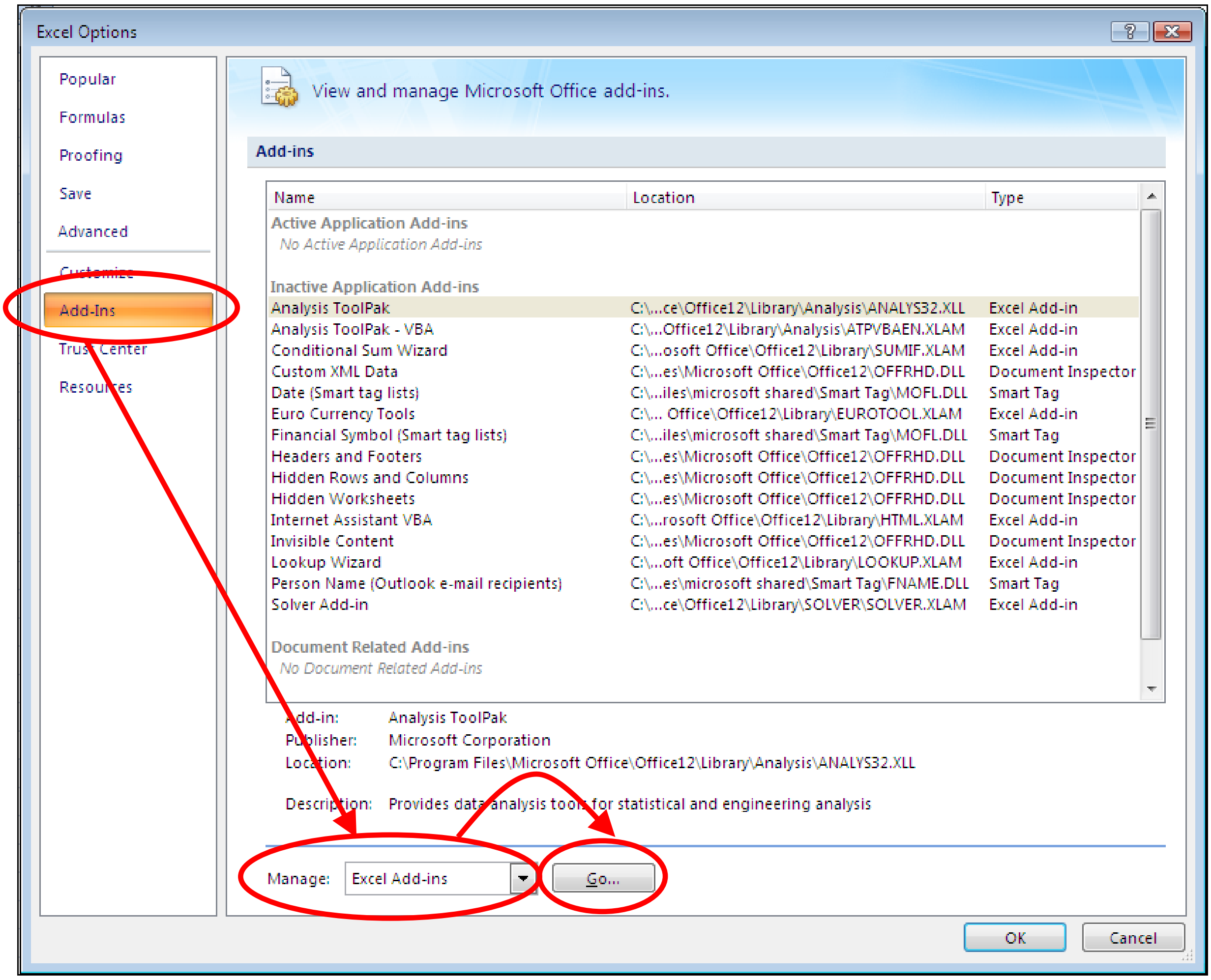


Figure 2.6: Registering FluidEXL*Graphics* as Add-In in Excel® 2007

- Click on "Add-Ins" in the next menu



Name	Location	Type
Active Application Add-ins		
No Active Application Add-ins		
Inactive Application Add-ins		
Analysis ToolPak	C:\...ce\Office12\Library\Analysis\ANALYS32.XLL	Excel Add-in
Analysis ToolPak - VBA	C:\...Office12\Library\Analysis\ATPVBAEN.XLAM	Excel Add-in
Conditional Sum Wizard	C:\...osoft Office\Office12\Library\SUMIF.XLAM	Excel Add-in
Custom XML Data	C:\...es\Microsoft Office\Office12\OFFRHD.DLL	Document Inspector
Date (Smart tag lists)	C:\...iles\microsoft shared\Smart Tag\MOFL.DLL	Smart Tag
Euro Currency Tools	C:\... Office\Office12\Library\EUROTOOL.XLAM	Excel Add-in
Financial Symbol (Smart tag lists)	C:\...iles\microsoft shared\Smart Tag\MOFL.DLL	Smart Tag
Headers and Footers	C:\...es\Microsoft Office\Office12\OFFRHD.DLL	Document Inspector
Hidden Rows and Columns	C:\...es\Microsoft Office\Office12\OFFRHD.DLL	Document Inspector
Hidden Worksheets	C:\...es\Microsoft Office\Office12\OFFRHD.DLL	Document Inspector
Internet Assistant VBA	C:\...rosoft Office\Office12\Library\HTML.XLAM	Excel Add-in
Invisible Content	C:\...es\Microsoft Office\Office12\OFFRHD.DLL	Document Inspector
Lookup Wizard	C:\...oft Office\Office12\Library\LOOKUP.XLAM	Excel Add-in
Person Name (Outlook e-mail recipients)	C:\...es\microsoft shared\Smart Tag\FNAME.DLL	Smart Tag
Solver Add-in	C:\...ce\Office12\Library\SOLVER\SOLVER.XLAM	Excel Add-in
Document Related Add-ins		
No Document Related Add-ins		

Add-in: Analysis ToolPak
Publisher: Microsoft Corporation
Location: C:\Program Files\Microsoft Office\Office12\Library\Analysis\ANALYS32.XLL

Description: Provides data analysis tools for statistical and engineering analysis

Manage: Excel Add-ins

Figure 2.7: Dialog window "Excel Options"

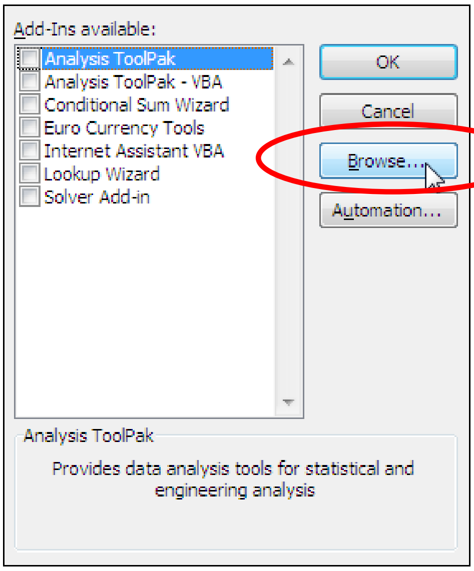
- Should it not be shown in the list automatically, choose and click on "Excel Add-ins" (found next to "Manage:" in the lower area of the menu)
- Then click the "Go…" button
- Click "Browse" in the following window and locate the destination folder, the standard being

C:\Program Files\FluidEXL_Graphics_Eng	(for English version of Windows)
C:\Programme\FluidEXL_Graphics	(for German version of Windows);

within that folder click on the file named

"FluidEXL_Graphics_Eng.xla"	(for English version of Windows)
"FluidEXL_Graphics.xla"	(for German version of Windows)

and then click the "OK" button.



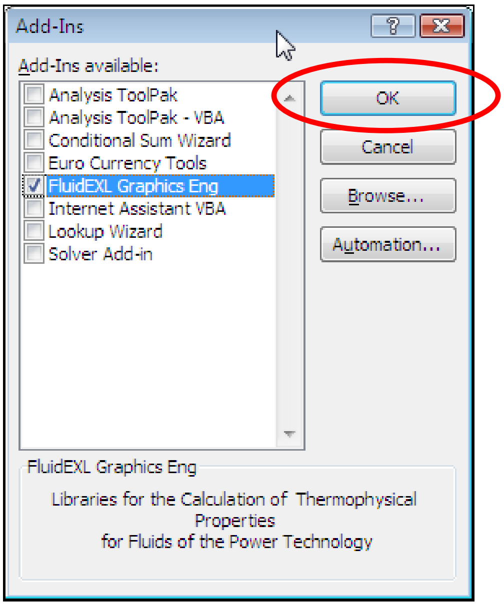
☐ Analysis ToolPak
☐ Analysis ToolPak - VBA
☐ Conditional Sum Wizard
☐ Euro Currency Tools
☐ Internet Assistant VBA
☐ Lookup Wizard
☐ Solver Add-in

Analysis ToolPak

Provides data analysis tools for statistical and engineering analysis

Figure 2.8: Dialog window "Add-Ins available"

- Now, "FluidEXL Graphics Eng" is shown in the Add-Ins list.
  (If a check-mark is situated in the box next to the name "FluidEXL Graphics", this Add-In will automatically be loaded whenever Excel starts. This will continue to occur unless the check-mark is removed from the box by clicking on it.)



☐ Analysis ToolPak
☐ Analysis ToolPak - VBA
☐ Conditional Sum Wizard
☐ Euro Currency Tools
☑ FluidEXL Graphics Eng
☐ Internet Assistant VBA
☐ Lookup Wizard
☐ Solver Add-in

FluidEXL Graphics Eng

Libraries for the Calculation of Thermophysical Properties
for Fluids of the Power Technology

Figure 2.9: Dialog window "Add-Ins"

- In order to register the Add-In click the "OK" button in the "Add-Ins" window.

In order to use FluidEXL*Graphics* in the following example, click on the menu item "Add-Ins" which is shown in the next image.

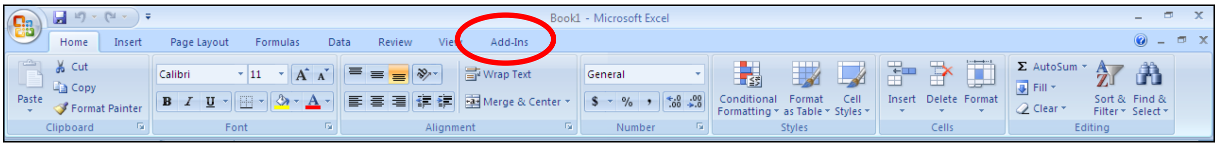


Figure 2.10: Menu item "Add-Ins"

In the upper menu region of Excel, the FluidEXL$^{\textit{Graphics}}$ menu bar will appear as marked with the red circle in the next image.

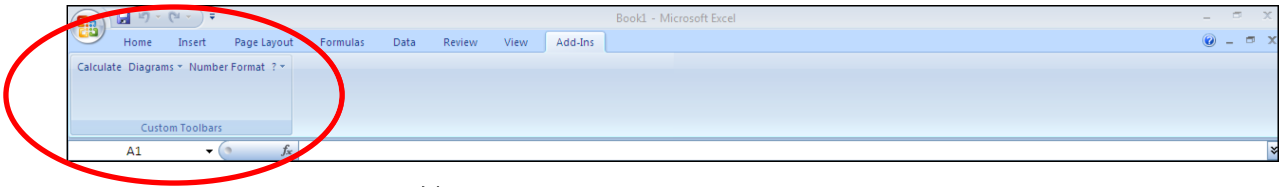


Figure 2.11: FluidEXL$^{\textit{Graphics}}$ menu bar

Installation of FluidEXL$^{\textit{Graphics}}$ in Excel (versions 2007 and later) is now finished. FluidEXL$^{\textit{Graphics}}$ can be used analogous to the description for using with earlier Excel versions.

Adding the LibHuGas library (FluidEXL$^{\textit{Graphics}}$ is already installed)

If FluidEXL$^{\textit{Graphics}}$ has already been installed in the June 2010 version, you only have to copy the following files provided in the extracted folder

CD_FluidEXL_Graphics_LibHuGas_Eng	(for English version of Windows®)
CD_FluidEXL_Graphics_LibHuGas	(for German version of Windows®)

into the folder you have chosen for the installation of FluidEXL$^{\textit{Graphics}}$ (the standard being

C:\Program Files\FluidEXL_Graphics_Eng	(for English version of Windows) or
C:\Programme\FluidEXL_Graphics	(for German version of Windows)),

using an appropriate program such as Explorer, Windows or Norton Commander:

FluidEXL_Graphics_Eng.xla	(for English version of Windows)
FluidEXL_Graphics.xla	(for German version of Windows)
LibHuGas.dll	
LibHuGas.hlp.	

From within Excel you can now select the "Humid Gas LibHuGas" DLL library property functions via the FluidEXL$^{\textit{Graphics}}$ menu bar (the example calculation can be found in chapter 2.5 on page 2/19).

2.3 The FluidEXL$^{\textit{Graphics}}$ Help System

As mentioned earlier, FluidEXL$^{\textit{Graphics}}$ also provides detailed online help functions.

If you are running Windows Vista or Windows 7, please note the paragraph

"Using the FluidEXL$^{\textit{Graphics}}$ Online-Help in Windows Vista or Windows 7."

For general information in Excel®

- Click on "?" and then "Help" in the FluidEXL$^{\textit{Graphics}}$ menu bar.

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

- Click "Calculate" in the FluidEXL$^{\textit{Graphics}}$ menu bar.
- Click on the "Humid Gas 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.
- If the "Office Assistant" is active, first double-click "Help on this feature" and in the next menu click "Help on selected function".

If the LibHuGas.hlp function help cannot be found, confirm the question whether you want to look for it yourself with "Yes". Select the LibHuGas.hlp file in the installation folder of FluidEXL*Graphics* in the window which is opened, in the standard case

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows)

and click "Yes" in order to complete the search.

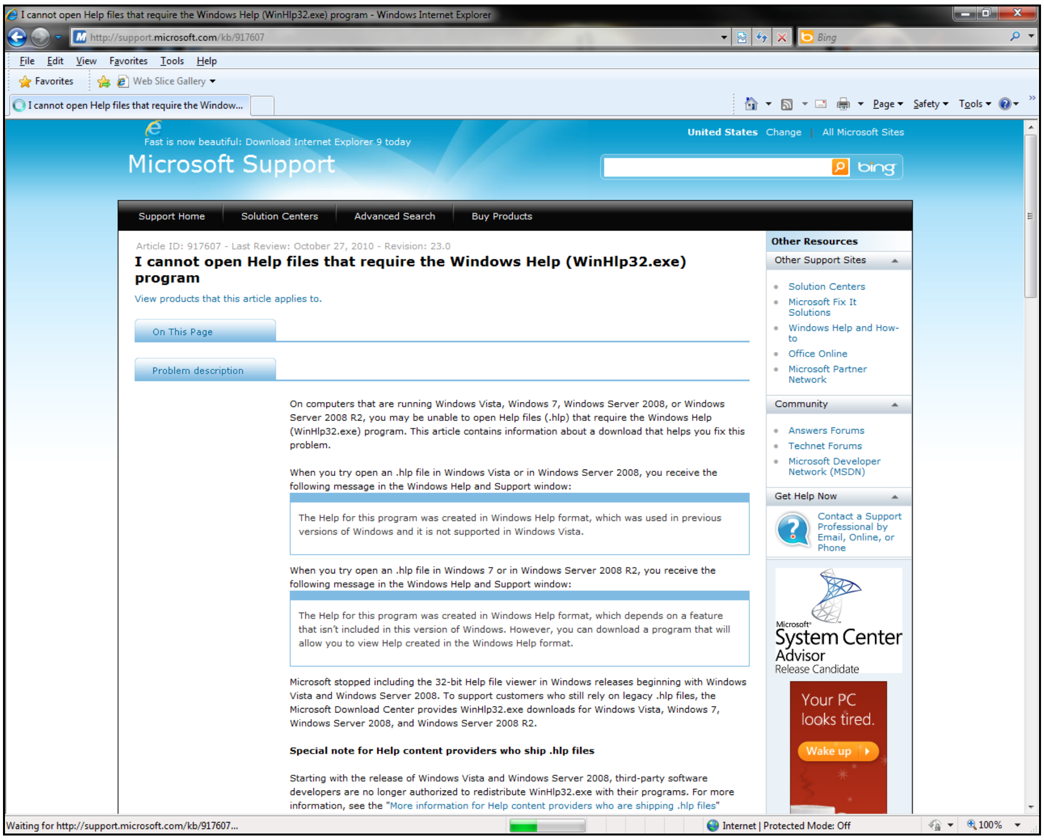
Using the FluidEXL*Graphics* Online Help in Windows Vista or Windows 7

If you are running Windows Vista or Windows 7 on your computer, you might not be able to open Help files. To view these files you have to install the Microsoft® Windows Help program which is provided by Microsoft®. Please carry out the following steps in order to download and install the Windows Help program.

Open Microsoft Internet Explorer® and go to the following address:

http://support.microsoft.com/kb/917607/

You will see the following web page:



Article ID: 917607 - Last Review: October 27, 2010 - Revision: 23.0

I cannot open Help files that require the Windows Help (WinHlp32.exe) program

View products that this article applies to.

On This Page

Problem description

On computers that are running Windows Vista, Windows 7, Windows Server 2008, or Windows Server 2008 R2, you may be unable to open Help files (.hlp) that require the Windows Help (WinHlp32.exe) program. This article contains information about a download that helps you fix this problem.

When you try open an .hlp file in Windows Vista or in Windows Server 2008, you receive the following message in the Windows Help and Support window:

> The Help for this program was created in Windows Help format, which was used in previous versions of Windows and it is not supported in Windows Vista.

When you try open an .hlp file in Windows 7 or in Windows Server 2008 R2, you receive the following message in the Windows Help and Support window:

> The Help for this program was created in Windows Help format, which depends on a feature that isn't included in this version of Windows. However, you can download a program that will allow you to view Help created in the Windows Help format.

Microsoft stopped including the 32-bit Help file viewer in Windows releases beginning with Windows Vista and Windows Server 2008. To support customers who still rely on legacy .hlp files, the Microsoft Download Center provides WinHlp32.exe downloads for Windows Vista, Windows 7, Windows Server 2008, and Windows Server 2008 R2.

Special note for Help content providers who ship .hlp files

Starting with the release of Windows Vista and Windows Server 2008, third-party software developers are no longer authorized to redistribute WinHlp32.exe with their programs. For more information, see the "More information for Help content providers who are shipping .hlp files"

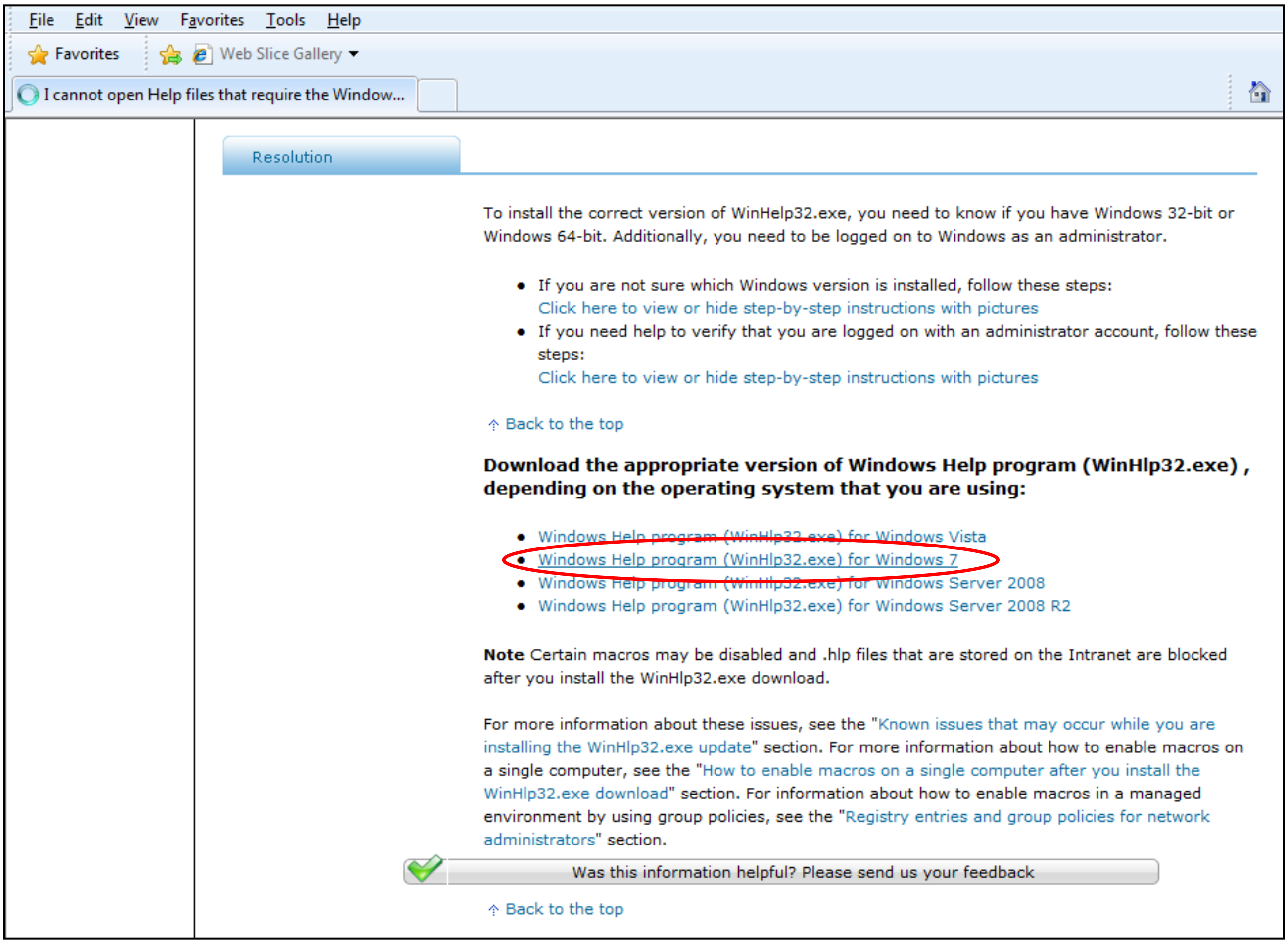
Figure 2.12: Microsoft® Support web page

Scroll down until you see the headline "Resolution." Here you can see the bold hint:

"Download the appropriate version of Windows Help program (WinHlp32.exe), depending on the operating system that you are using:"

The following description relates to Windows® 7. The procedure is analogous for Windows® Vista.

Click on the link "Windows Help program (WinHlp32.exe) for Windows 7" (see Figure 2.13).



To install the correct version of WinHelp32.exe, you need to know if you have Windows 32-bit or Windows 64-bit. Additionally, you need to be logged on to Windows as an administrator.

- If you are not sure which Windows version is installed, follow these steps:
  Click here to view or hide step-by-step instructions with pictures
- If you need help to verify that you are logged on with an administrator account, follow these steps:
  Click here to view or hide step-by-step instructions with pictures

Back to the top

Download the appropriate version of Windows Help program (WinHlp32.exe) , depending on the operating system that you are using:

- Windows Help program (WinHlp32.exe) for Windows Vista
- Windows Help program (WinHlp32.exe) for Windows 7
- Windows Help program (WinHlp32.exe) for Windows Server 2008
- Windows Help program (WinHlp32.exe) for Windows Server 2008 R2

Note Certain macros may be disabled and .hlp files that are stored on the Intranet are blocked after you install the WinHlp32.exe download.

For more information about these issues, see the "Known issues that may occur while you are installing the WinHlp32.exe update" section. For more information about how to enable macros on a single computer, see the "How to enable macros on a single computer after you install the WinHlp32.exe download" section. For information about how to enable macros in a managed environment by using group policies, see the "Registry entries and group policies for network administrators" section.

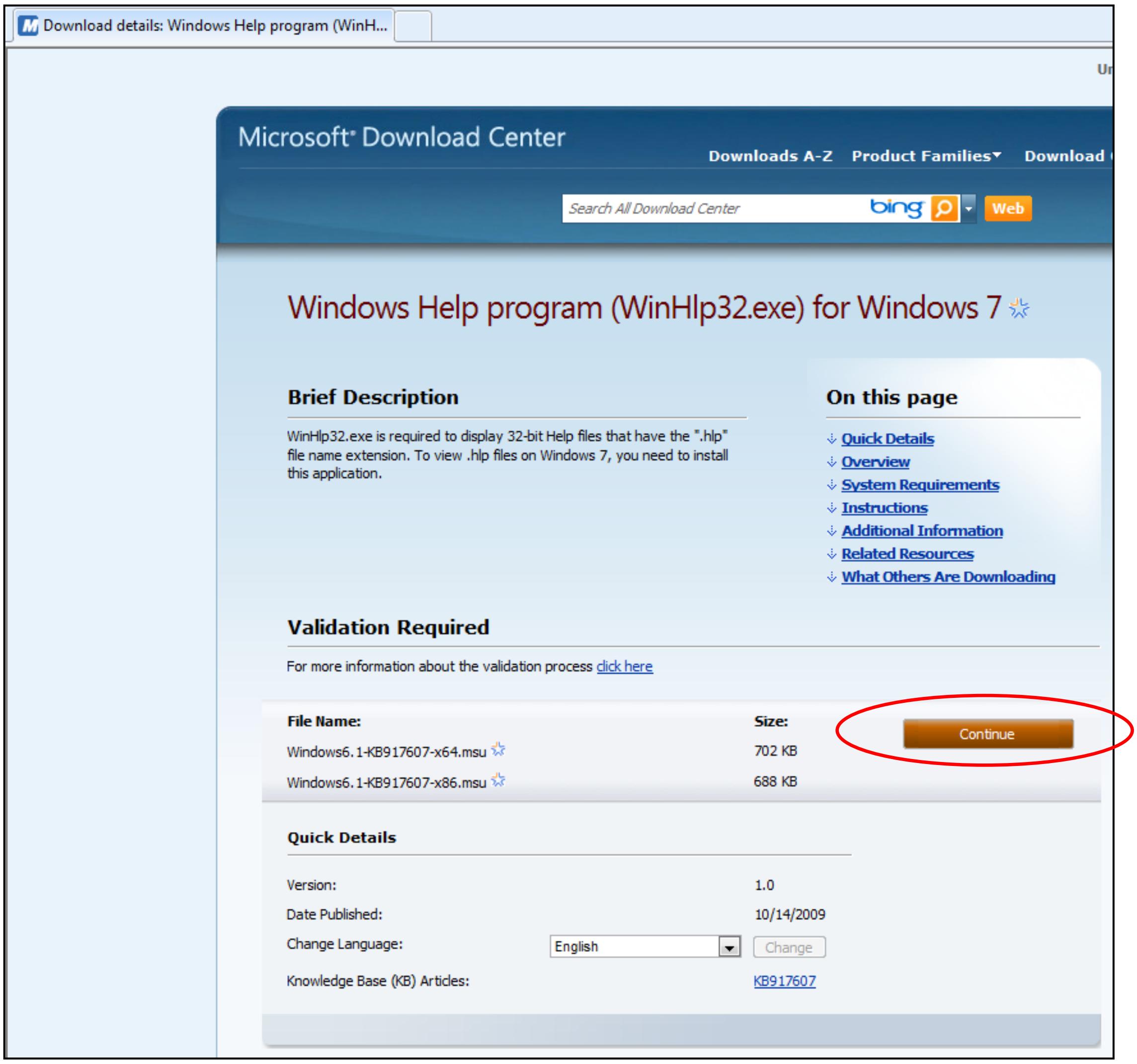
Back to the top

Figure 2.13: Selecting your Windows version

You will be forwarded to the Microsoft Download Center where you can download the Microsoft Windows Help program.

First, a validation of your Windows License is required.

To do this click on the "Continue" button (see Figure 2.14).



Windows Help program (WinHlp32.exe) for Windows 7

Brief Description

WinHlp32.exe is required to display 32-bit Help files that have the ".hlp" file name extension. To view .hlp files on Windows 7, you need to install this application.

Validation Required

For more information about the validation process click here

File Name:	Size:
Windows6.1-KB917607-x64.msu	702 KB
Windows6.1-KB917607-x86.msu	688 KB

Quick Details

Version: 1.0

Date Published: 10/14/2009

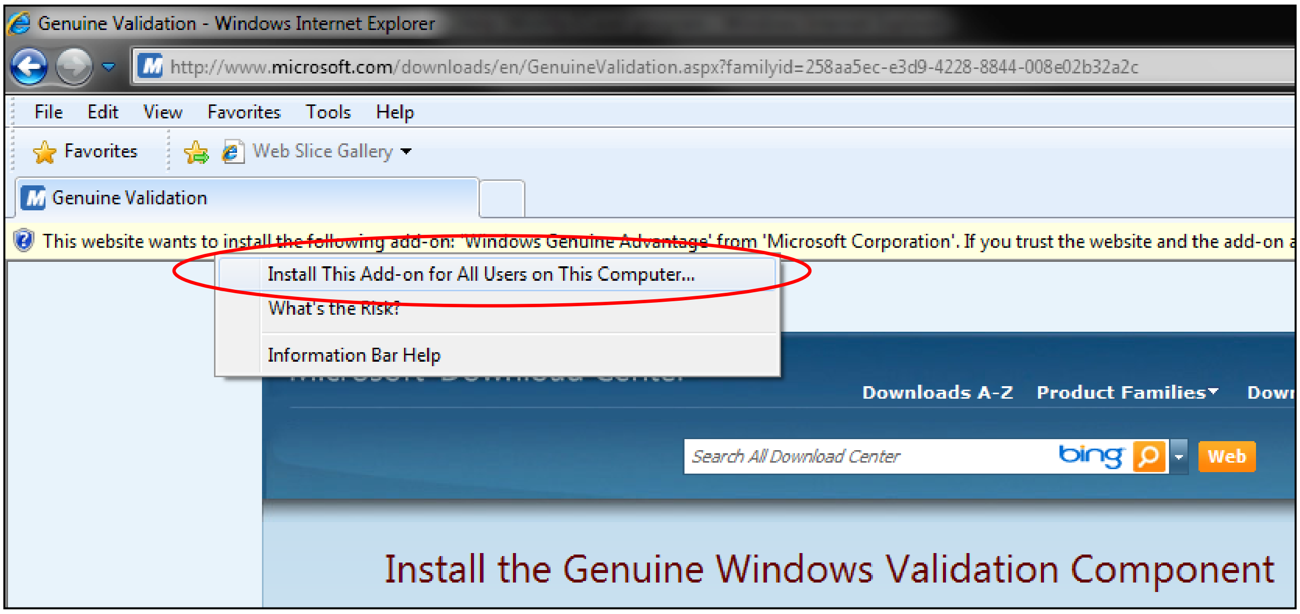
Change Language: English

Knowledge Base (KB) Articles: KB917607

Figure 2.14: Microsoft® Download Center

You will be forwarded to a web page with instructions on how to install the Genuine Windows Validation Component.

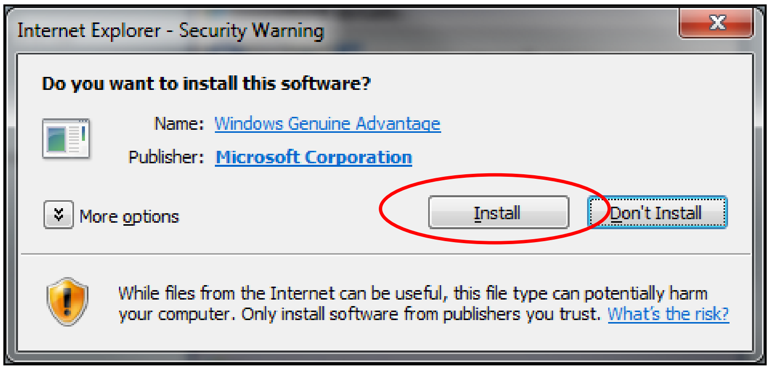
At the top of your Windows Internet Explorer you will see a yellow information bar. Right-click this bar and select "Install ActiveX Control" in the context menu (see Figure 2.15).



This website wants to install the following add-on: 'Windows Genuine Advantage' from 'Microsoft Corporation'. If you trust the website and the add-on a

Figure 2.15: Installing the Genuine Windows Validation Component

A dialog window appears in which you will be asked if you want to install the software. Click the "Install" button to continue (see Figure 2.16).



Do you want to install this software?

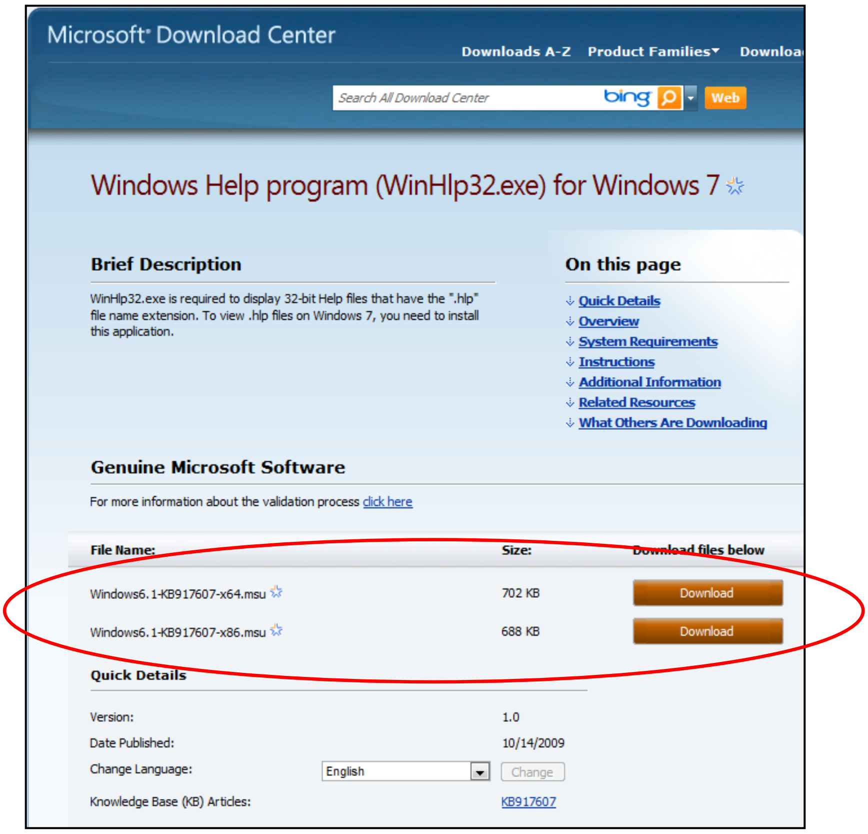
Name: Windows Genuine Advantage

Publisher: Microsoft Corporation

While files from the Internet can be useful, this file type can potentially harm your computer. Only install software from publishers you trust. What's the risk?

Figure 2.16: Internet Explorer – Security Warning

After the validation has been carried out you will be able to download the appropriate version of Windows Help program (see Figure 2.17).



Windows Help program (WinHlp32.exe) for Windows 7

Brief Description

WinHlp32.exe is required to display 32-bit Help files that have the ".hlp" file name extension. To view .hlp files on Windows 7, you need to install this application.

On this page

- Quick Details
- Overview
- System Requirements
- Instructions
- Additional Information
- Related Resources
- What Others Are Downloading

Genuine Microsoft Software

For more information about the validation process click here

File Name:	Size:	Download files below
Windows6.1-KB917607-x64.msu	702 KB	Download
Windows6.1-KB917607-x86.msu	688 KB	Download

Quick Details

Version:	1.0
Date Published:	10/14/2009
Change Language:	English
Knowledge Base (KB) Articles:	KB917607

Figure 2.17: Downloading the Windows Help program

To download and install the correct file you need to know which Windows version (32-bit or 64-bit) you are running on your computer.

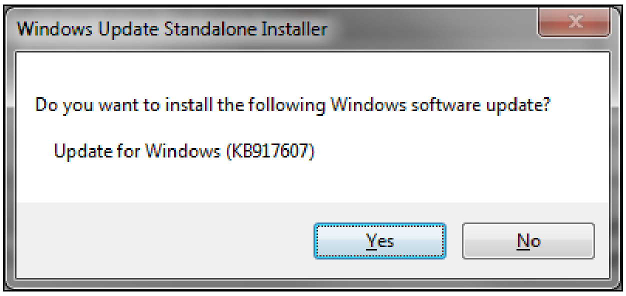
If you are running a 64-bit operating system, please download the file
Windows6.1-KB917607-x64.msu.

If you are running a 32-bit operating system, please download the file
Windows6.1-KB917607-x86.msu.

In order to run the installation of the Windows Help program double-click the file you have just downloaded on your computer:

Windows6.1-KB917607-x64.msu (for 64-bit operating system)
Windows6.1-KB917607-x86.msu. (for 32-bit operating system).

Installation starts with a window searching for updates on your computer. After the program has finished searching you may see the following window.



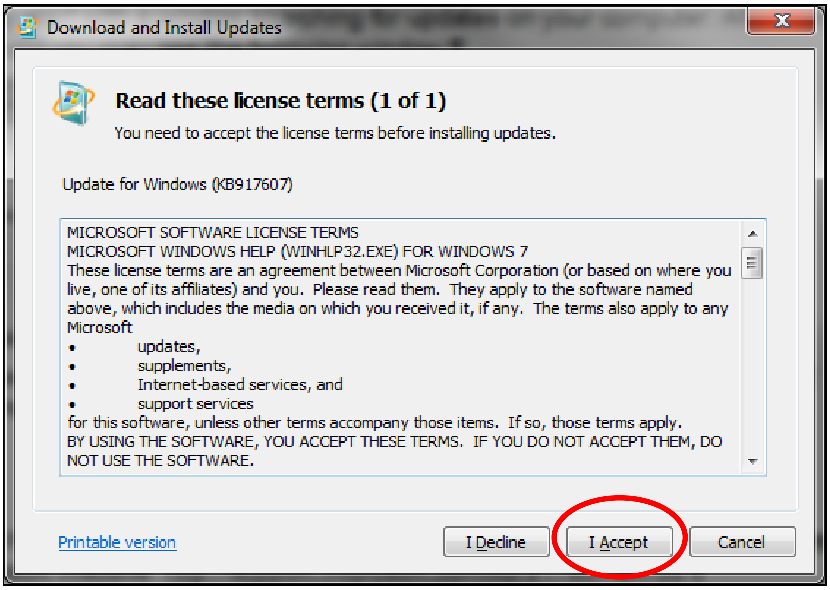
Do you want to install the following Windows software update?

Update for Windows (KB917607)

Figure 2.18: Windows Update Standalone Installer

In this case, the installation can be continued by clicking the "Yes" button.
(If you have already installed this update, you will see the message "Update for Windows (KB917607) is already installed on this computer.")

In the next window you have to accept the Microsoft license terms before installing the update by clicking on "I Accept" (see Figure 2.19)



Read these license terms (1 of 1)

You need to accept the license terms before installing updates.

Update for Windows (KB917607)

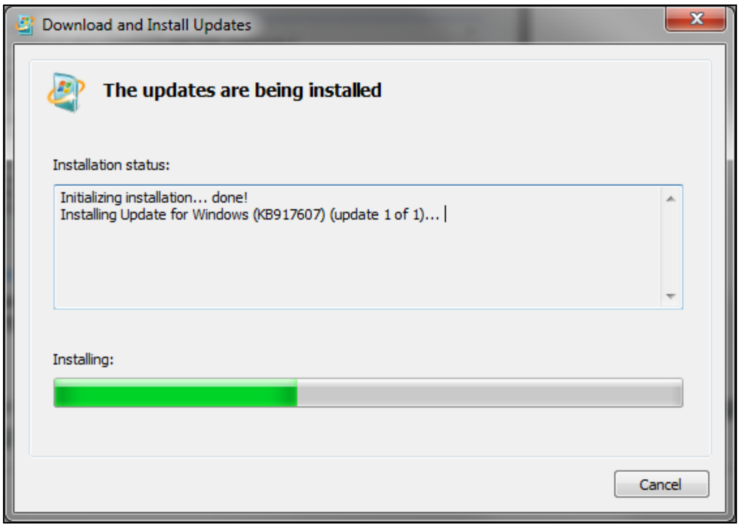
MICROSOFT SOFTWARE LICENSE TERMS
MICROSOFT WINDOWS HELP (WINHLP32.EXE) FOR WINDOWS 7
These license terms are an agreement between Microsoft Corporation (or based on where you live, one of its affiliates) and you. Please read them. They apply to the software named above, which includes the media on which you received it, if any. The terms also apply to any Microsoft

- updates,
- supplements,
- Internet-based services, and
- support services

for this software, unless other terms accompany those items. If so, those terms apply.
BY USING THE SOFTWARE, YOU ACCEPT THESE TERMS. IF YOU DO NOT ACCEPT THEM, DO NOT USE THE SOFTWARE.

Figure 2.19: Windows License Terms

Installation starts once you have clicked the "I Accept" button (see Figure 2.20).



The updates are being installed

```
Initializing installation... done!
Installing Update for Windows (KB917607) (update 1 of 1)...
```

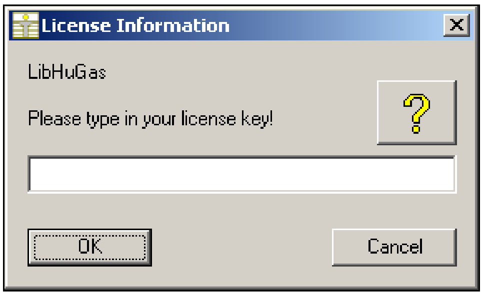
Figure 2.20: Installation process

After the Windows Help program has been installed, the notification "Installation complete" will appear. Confirm this by clicking the "Close" button.

The installation of the Windows Help program has been completed and you will now be able to open the Help files.

2.4 Licensing the LibHuGas Property Library

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).

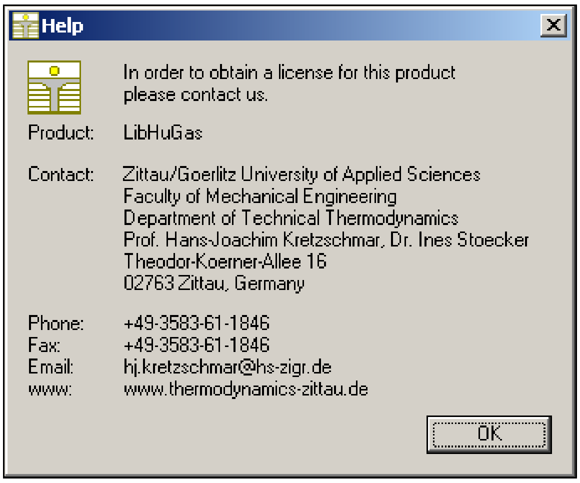


LibHuGas

Please type in your license key!

Figure 2.21: "License Information" window

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



In order to obtain a license for this product
please contact us.

Product: LibHuGas

Contact: Zittau/Goerlitz University of Applied Sciences
Faculty of Mechanical Engineering
Department of Technical Thermodynamics
Prof. Hans-Joachim Kretzschmar, Dr. Ines Stoecker
Theodor-Koerner-Allee 16
02763 Zittau, Germany

Phone: +49-3583-61-1846
Fax: +49-3583-61-1846
Email: hj.kretzschmar@hs-zigr.de
www: www.thermodynamics-zittau.de

Figure 2.22: "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.hlp

in the installation folder of FluidEXL*Graphics* (the standard being

C:\Program Files\FluidEXL_Graphics_Eng	(for English version of Windows) or
C:\Programme\FluidEXL_Graphics	(for English version of Windows)),

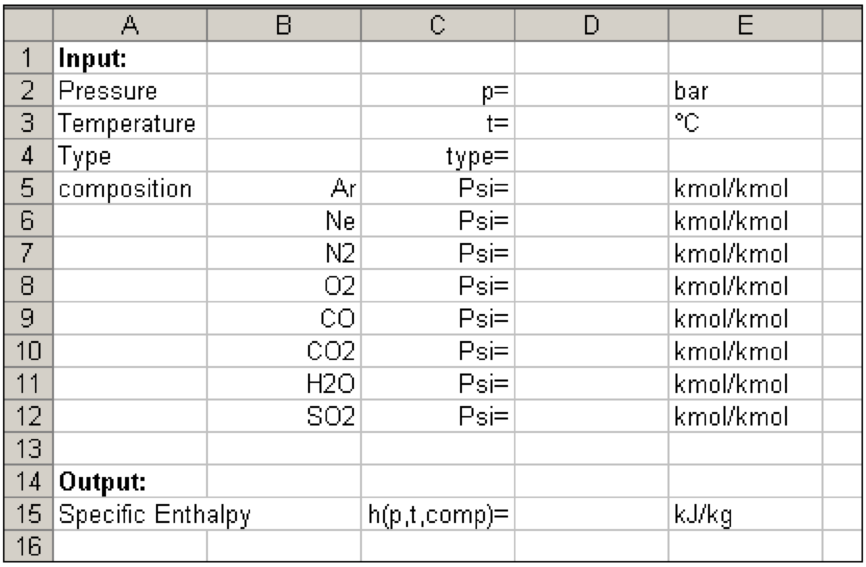
using an appropriate program such as Explorer® or Norton Commander.

2.5 Example: Calculation of *h* = f(*p*,*t*,type,comp(1:8))

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 2.23



	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 2.23: 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)

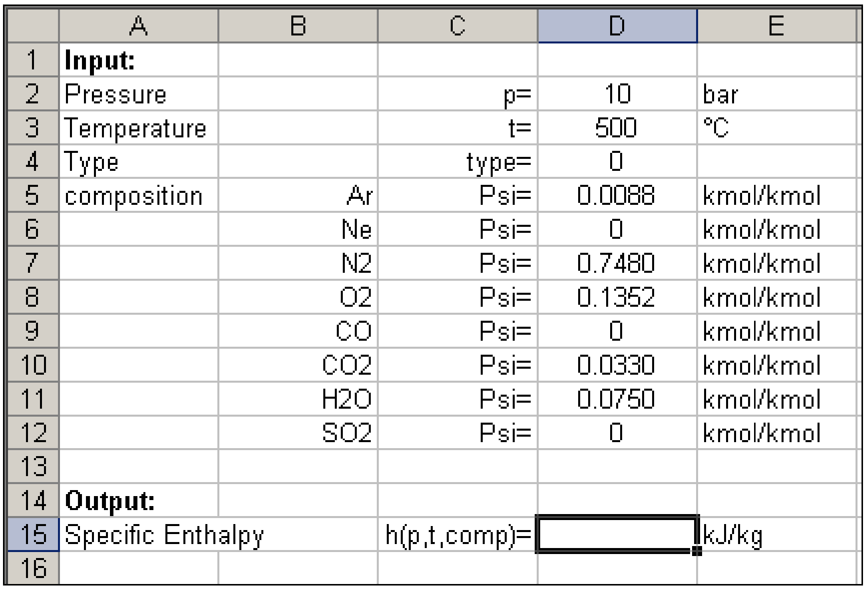
  ⇒ e.g.: Enter the value 500 into cell D3
- Enter the value for type into a cell
  (Definition of type: 0 – composition as mole fractions
  1 – composition as mass fractions)

  ⇒ 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

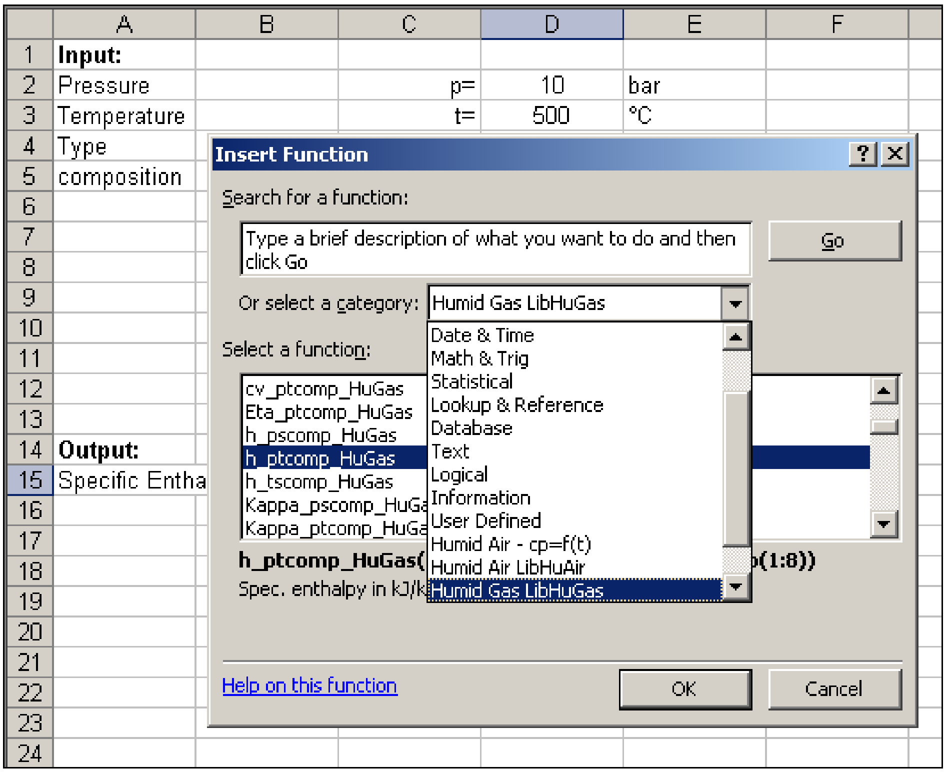
The Excel sheet should now look as shown in Figure 2.24.



	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 2.24: 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 2.25)
- Search and click the "h_ptcomp_HuGas" function under "Select a function:"



	A	B	C	D	E	F
1	**Input:**					
2	Pressure		p=	10	bar	
3	Temperature		t=	500	°C	
4	Type					
5	composition					
14	**Output:**					
15	Specific Entha					

Insert Function

Search for a function: Type a brief description of what you want to do and then click Go

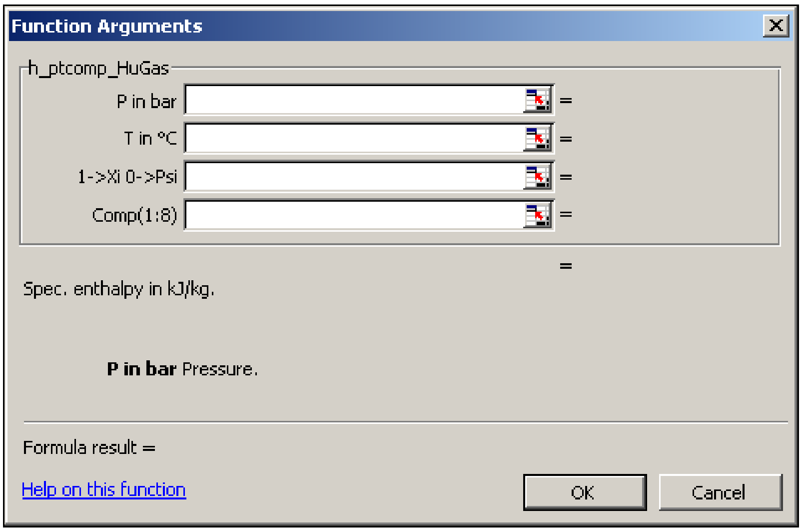
Or select a category: Humid Gas LibHuGas

h_ptcomp_HuGas(…**p(1:8))**

Spec. enthalpy in kJ/k…

Figure 2.25: Choice of library and function name

- Click the "OK" button
  The "Function Arguments" window will now appear (Figure 2.26).



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 =

Figure 2.26: 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

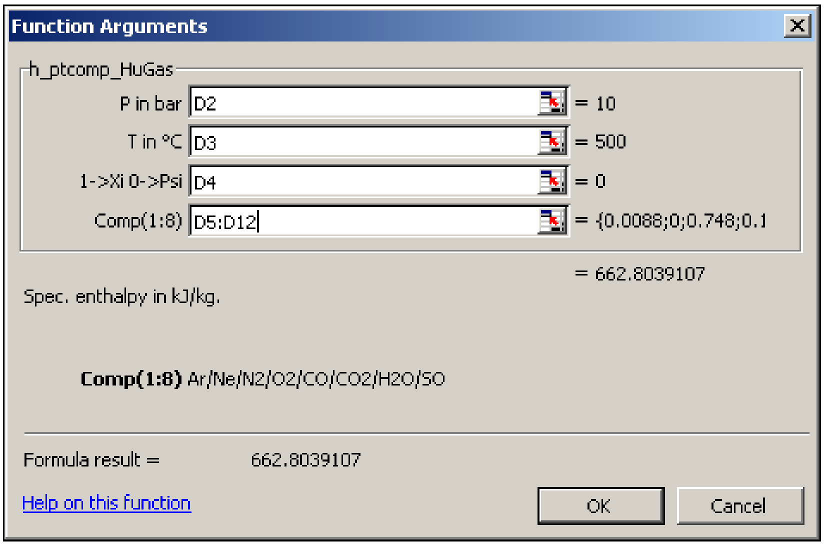
- The mouse arrow changes into a cross.

  By pressing the left mouse button, mark the other cells including mole or mass fractions for Ne, N_2, O_2, CO, CO_2, H_2O and SO_2 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".



h_ptcomp_HuGas

P in bar D2 = 10

T in °C D3 = 500

1->Xi 0->Psi D4 = 0

Comp(1:8) D5:D12 = {0.0088;0;0.748;0.1

= 662.8039107

Spec. enthalpy in kJ/kg.

Comp(1:8) Ar/Ne/N2/O2/CO/CO2/H2O/SO

Formula result = 662.8039107

Figure 2.27: 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*,type,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.

- Click the cell or select and click on the cells you wish to format
- 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 - Fix 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.

2.6 Removing FluidEXL^{Graphics}

Should you wish to remove only the library LibHuGas the files

LibHuGas.dll
LibHuGas.hlp

in the directory selected for the installation of FluidEXL^{Graphics}, in the standard case

C:\Program Files\FluidEXL_Graphics_Eng	(for English version of Windows®)
C:\Programme\FluidEXL_Graphics	(for German version of Windows)

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

Unregistering 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	(for English version of Windows®) or
FluidEXL_Graphics.xla	(for German version of Windows)

has to be canceled in Excel.

In order to do that, 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"	(for English version of Windows) or
"FluidEXL Graphics"	(for German version of Windows)

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.

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

"FluidEXL Graphics Eng"	(for English version of Windows) or
"FluidEXL Graphics"	(for German version of Windows)

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". Afterwards, we recommend closing Excel.

Within the next step delete the files

LibHuGas.dll
LibHuGas.hlp

in the directory selected for the installation of FluidEXL^{Graphics} (in the standard case

C:\Program Files\FluidEXL_Graphics_Eng	(for English version of Windows)
C:\Programme\FluidEXL_Graphics	(for German version of Windows)),

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

In order to remove FluidEXL^{Graphics} from Windows and the hard disk 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"	(for English version of Windows) or
"FluidEXL Graphics"	(for German version of Windows)

by clicking on it and click the "Add/Remove…" button. In the following dialog box click "Automatic" and thereafter "Next >". Click "Finish" in the "Perform Uninstall" window. 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$^{\textit{Graphics}}$ has been removed.

Unregistering FluidEXL$^{\textit{Graphics}}$ as Add-In in Excel$^{®}$ 2007 (or later versions)

In order to unregister the FluidEXL$^{\textit{Graphics}}$ Add-In in Excel$^{®}$ 2007 start Excel and carry out the following commands:

- Click the Windows Office$^{®}$ button in the upper left corner of Excel
- Click on the "Excel Options" button in the menu which appears

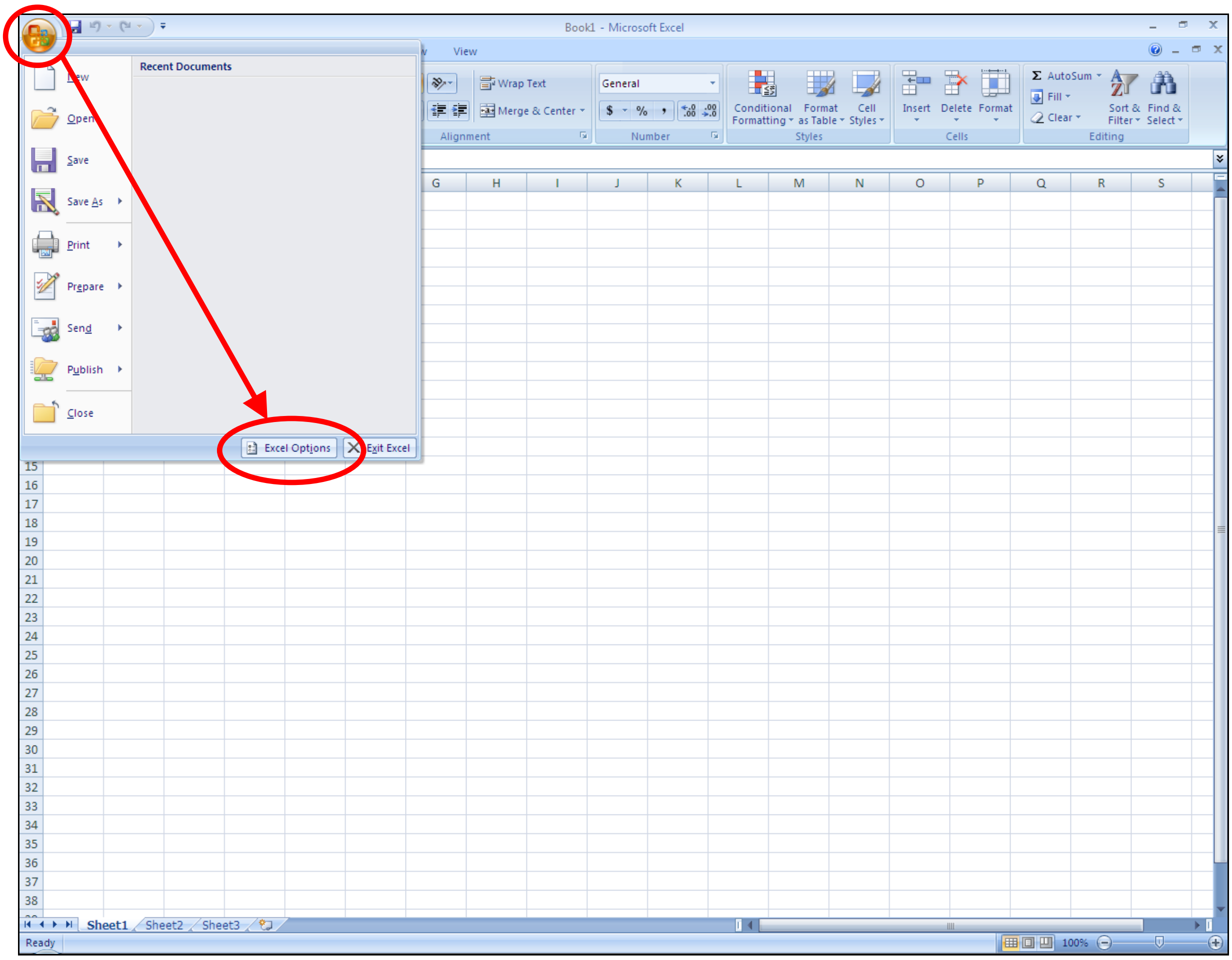
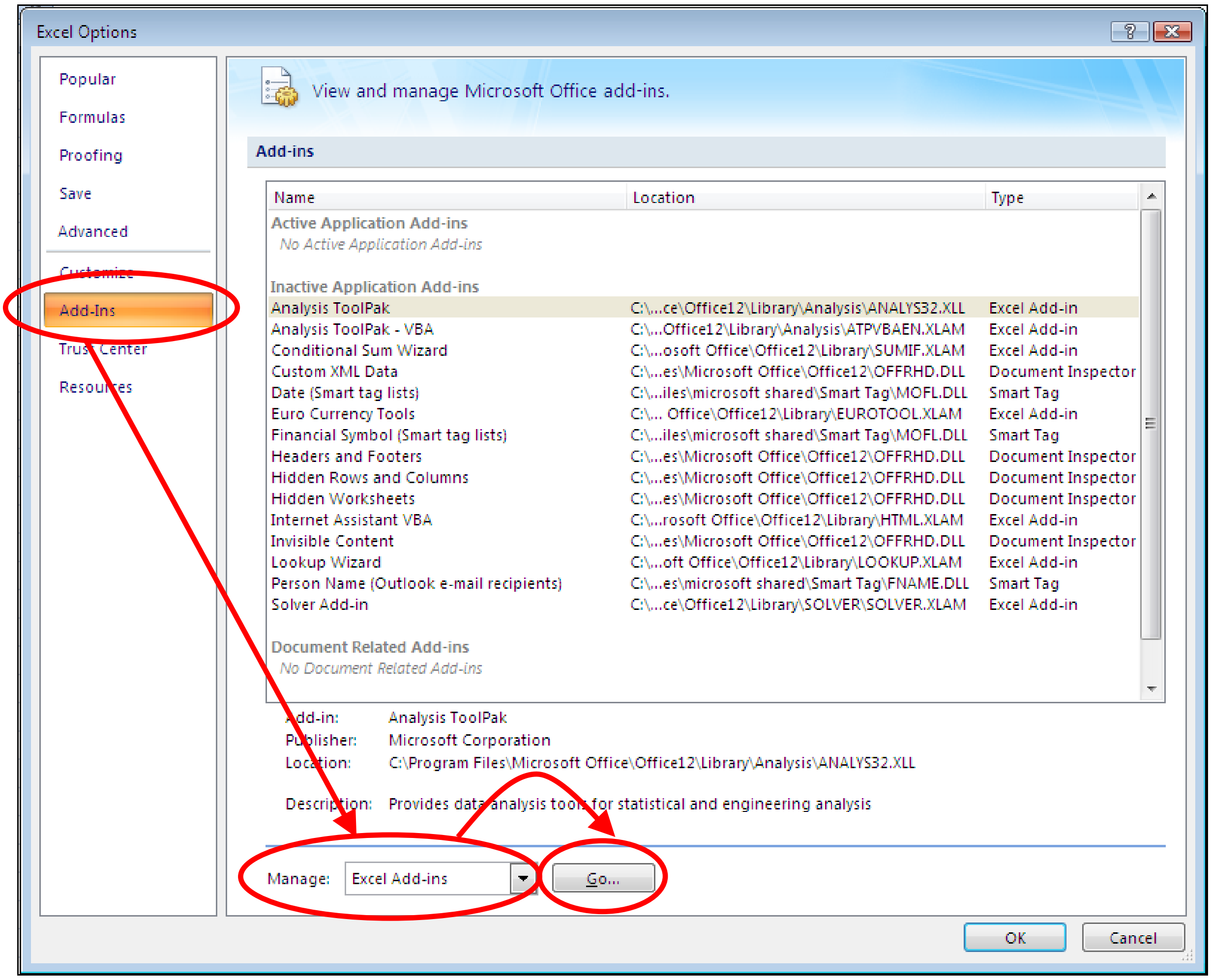


Figure 2.28: Unregistering FluidEXL$^{\textit{Graphics}}$ as Add-In in Excel$^{®}$ 2007

- Click on "Add-Ins" in the next menu



Name	Location	Type
Active Application Add-ins		
No Active Application Add-ins		
Inactive Application Add-ins		
Analysis ToolPak	C:\...ce\Office12\Library\Analysis\ANALYS32.XLL	Excel Add-in
Analysis ToolPak - VBA	C:\...Office12\Library\Analysis\ATPVBAEN.XLAM	Excel Add-in
Conditional Sum Wizard	C:\...osoft Office\Office12\Library\SUMIF.XLAM	Excel Add-in
Custom XML Data	C:\...es\Microsoft Office\Office12\OFFRHD.DLL	Document Inspector
Date (Smart tag lists)	C:\...iles\microsoft shared\Smart Tag\MOFL.DLL	Smart Tag
Euro Currency Tools	C:\... Office\Office12\Library\EUROTOOL.XLAM	Excel Add-in
Financial Symbol (Smart tag lists)	C:\...iles\microsoft shared\Smart Tag\MOFL.DLL	Smart Tag
Headers and Footers	C:\...es\Microsoft Office\Office12\OFFRHD.DLL	Document Inspector
Hidden Rows and Columns	C:\...es\Microsoft Office\Office12\OFFRHD.DLL	Document Inspector
Hidden Worksheets	C:\...es\Microsoft Office\Office12\OFFRHD.DLL	Document Inspector
Internet Assistant VBA	C:\...rosoft Office\Office12\Library\HTML.XLAM	Excel Add-in
Invisible Content	C:\...es\Microsoft Office\Office12\OFFRHD.DLL	Document Inspector
Lookup Wizard	C:\...oft Office\Office12\Library\LOOKUP.XLAM	Excel Add-in
Person Name (Outlook e-mail recipients)	C:\...es\microsoft shared\Smart Tag\FNAME.DLL	Smart Tag
Solver Add-in	C:\...ce\Office12\Library\SOLVER\SOLVER.XLAM	Excel Add-in
Document Related Add-ins		
No Document Related Add-ins		

Add-in: Analysis ToolPak
Publisher: Microsoft Corporation
Location: C:\Program Files\Microsoft Office\Office12\Library\Analysis\ANALYS32.XLL

Description: Provides data analysis tools for statistical and engineering analysis

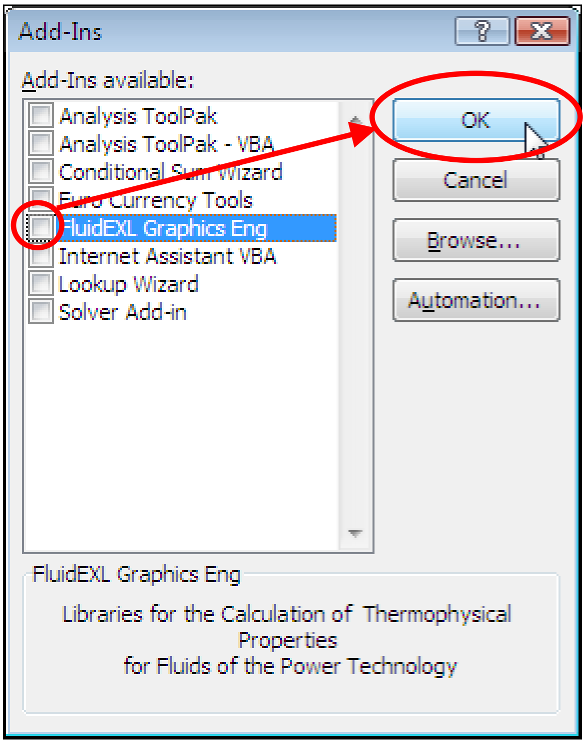
Manage: Excel Add-ins

Figure 2.29: Dialog window "Add-Ins"

- If it is not shown in the list automatically, choose 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" (for English version of Windows)
"FluidEXL Graphics" (for German version of Windows)

in the window which now appears. Click the "OK" button to confirm your entry.



☐ Analysis ToolPak
☐ Analysis ToolPak - VBA
☐ Conditional Sum Wizard
☐ Euro Currency Tools
☐ FluidEXL Graphics Eng
☐ Internet Assistant VBA
☐ Lookup Wizard
☐ Solver Add-in

FluidEXL Graphics Eng

Libraries for the Calculation of Thermophysical Properties
for Fluids of the Power Technology

Figure 2.30: 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"	(for English version of Windows)
"FluidEXL Graphics"	(for German version of Windows)

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.

3. Program Documentation

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

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

Function Name:

a_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

type = 0 → composition as mole fraction

= 1 → composition as mass fraction

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

Result:

a_ptcomp_HuGas - Thermal diffusivity in m^2/s

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

- Thermal diffusivity $a = \dfrac{\lambda}{\rho \cdot c_p}$, model of ideal mixture of real fluids
- Valid only for unsaturated humid gas ($\psi_\mathrm{w} \le \psi_\mathrm{w,sat}$)

Result for incorrect input values:

$$\mathrm{a\_ptcomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

cp_hscomp_HuGas

Input values:

h - Specific enthalpy h in kJ/kg

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

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

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

Result:

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

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

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

Result for incorrect input values:

$$\text{cp\_hscomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

cp_phcomp_HuGas

Input values:

p - Pressure p in bar

h - Specific enthalpy h in kJ/kg

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

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

Result:

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

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

$$\text{cp\_phcomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

cp_pscomp_HuGas

Input values:

p - Pressure p in bar

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

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

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

Result:

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

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

$$\text{cp\_pscomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

cp_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

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

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

Result:

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

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values:

$$\text{cp\_ptcomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

cp_tscomp_HuGas

Input values:

t - Temperature t in °C

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

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

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

Result:

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

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

$$\text{cp\_tscomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

cv_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

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

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

Result:

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

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values:

$$cv\_ptcomp\_HuGas = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

Eta_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

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

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

Result:

Eta_ptcomp_HuGas - Dynamic viscosity in Pa s

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values:

$$\text{Eta\_ptcomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

h_pscomp_HuGas

Input values:

p - Pressure *p* in bar

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

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

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

Result:

h_pscomp_HuGas - specific enthalpy in kJ/kg

Range of validity:

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

Pressure *p*: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

$$\text{h\_pscomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

h_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

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

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

Result:

h_ptcomp_HuGas - Specific enthalpy in kJ/kg

Range of validity:

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

Pressure p: $0.01\ \text{bar} \leq p \leq 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values:

$$h\_ptcomp\_HuGas = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

h_tscomp_HuGas

Input values:

t - Temperature *t* in °C

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

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

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

Result:

h_tscomp_HuGas - Specific enthalpy in kJ/kg

Range of validity:

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

Pressure *p*: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

$$\text{h\_tscomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

Kappa_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

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

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

Result:

Kappa_ptcomp_HuGas - Isentropic exponent

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

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

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

Result for incorrect input values:

$$\text{kappa\_ptcomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

Kappa_pscomp_HuGas

Input values:

p - Pressure p in bar

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

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

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

Result:

Kappa_pscomp_HuGas - Isentropic exponent

Range of validity:

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

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

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

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

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

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

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

Result for incorrect input values:

$$\text{kappa\_pscomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

Lambda_ptcomp_HuGas

Input values:

p	- Pressure p in bar
t	- Temperature t in °C
type	= 0 → composition as mole fraction = 1 → composition as mass fraction
comp	- Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Lambda_ptcomp_HuGas - Thermal conductivity in W/(m K)

Range of validity:

Temperature t :	$-70\ °C \le t \le 3026.85\ °C$
Pressure p:	$0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Result for incorrect input values:

$$\text{lambda\_ptcomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

M_comp_HuGas

Input values:

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

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

Result:

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

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

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

Result:

Ny_ptcomp_HuGas - Kinematic viscosity in m^2/s

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Result for incorrect input values:

$$\text{Ny\_ptcomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

p_hscomp_HuGas

Input values:

h - Specific enthalpy h in kJ/kg

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

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

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

Result:

p_hscomp_HuGas - Pressure in bar

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

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

$$\text{p\_hscomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

p_tscomp_HuGas

Input values:

t - Temperature *t* in °C

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

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

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

Result:

p_tscomp_HuGas - Pressure in bar

Range of validity:

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

Pressure *p*: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of *p* from s(p,t,comp) and calculation:
- for unsaturated and saturated humid gas ($\psi_w \le \psi_{w,sat}$) 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:

$$\text{p\_tscomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

pdsat_pt_HuGas

Input values:

p - Pressure *p* in bar
t - Temperature *t* in °C

Result:

pdsat_pt_HuGas - Saturation pressure of water in bar

Range of validity:

Temperature *t* : $-70\ °\mathrm{C} \le t \le 3026.85\ °\mathrm{C}$
Pressure *p*: $0.01\ \mathrm{bar} \le p \le 1000\ \mathrm{bar}$

Comments:

$p_{\mathrm{dsat}}(p,t)$ for $t \ge 0.01$ °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:

$$\mathrm{pdsat\_pt\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

Phi_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

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

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

Result:

Phi_ptcomp_HuGas - Relative humidity in %

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

with $p_{dsat}(p,t)$ for $t \ge 0.01\ °C$ - 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:

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

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

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

Function Name:

Pr_ptcomp_HuGas

Input values:

p	- Pressure p in bar
t	- Temperature t in °C
type	= 0 → composition as mole fraction = 1 → composition as mass fraction
comp	- Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Pr_ptcomp_HuGas - Prandtl-number

Range of validity:

Temperature t :	$-70\ °C \le t \le 3026.85\ °C$
Pressure p:	$0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Result for incorrect input values:

$$\text{Pr\_ptcomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

R_comp_HuGas

Input values:

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

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

Result:

R_comp_HuGas - Gas constant in kJ/(kg K)

Result for incorrect input values:

$$\mathrm{R\_comp\_HuGas} = -1 \cdot 10^{100}$$

Reference: [32]

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

Function Name:

Region_hscomp_HuGas

Input values:

h - Specific enthalpy *h* in kJ/kg

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

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

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

Result:

Region_hscomp_HuGas - State point of humid gas mixture

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

Range of validity:

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

Pressure *p*: $0.01\ \text{bar} \leq p \leq 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Result for incorrect input values:

Region_hscomp_HuGas = 0

Reference:

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

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

Function Name:

Region_phcomp_HuGas

Input values:

p - Pressure *p* in bar

h - Specific enthalpy *h* in kJ/kg

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

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

Result:

Region_phcomp_HuGas - State point of humid gas mixture

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

Range of validity:

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

Pressure *p*: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Result for incorrect input values:

Region_phcomp_HuGas = 0

Reference:

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

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

Function Name:

Region_pscomp_HuGas

Input values:

p	- Pressure *p* in bar
s	- Specific entropy *s* in kJ/(kg K)
type	= 0 → composition as mole fraction = 1 → composition as mass fraction
comp	- Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Region_pscomp_HuGas - State point of humid gas mixture

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

Range of validity:

Temperature *t* :	$-70\ °C \leq t \leq 3026.85\ °C$
Pressure *p*:	$0.01\ \text{bar} \leq p \leq 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Result for incorrect input values:

Region_pscomp_HuGas = 0

Reference:

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

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

Function Name:

Region_ptcomp_HuGas

Input values:

p	- Pressure p in bar
t	- Temperature t in °C
type	= 0 → composition as mole fraction = 1 → composition as mass fraction
comp	- Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

Region_ptcomp_HuGas - State point of humid gas mixture

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

Range of validity:

Temperature t :	$-70\ °C \le t \le 3026.85\ °C$
Pressure p:	$0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values:

Region_ptcomp_HuGas = 0

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

Function Name:

Region_tscomp_HuGas

Input values:

t - Temperature *t* in °C

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

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

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

Result:

Region_tscomp_HuGas - State point of humid gas mixture

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

Range of validity:

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

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

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Result for incorrect input values:

Region_tscomp_HuGas = 0

Reference:

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

Density ρ = f(p,t,type,comp(1:8))

Function Name:

rho_ptcomp_HuGas

Input values:

p	- Pressure p in bar
t	- Temperature t in °C
type	= 0 → composition as mole fraction = 1 → composition as mass fraction
comp	- Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

rho_ptcomp_HuGas - Density in kg/m³

Range of validity:

Temperature t :	$-70\ °C \le t \le 3026.85\ °C$
Pressure p:	$0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values:

$$\text{rho\_ptcomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

s_phcomp_HuGas

Input values:

p	- Pressure p in bar
h	- Specific enthalpy h in kJ/kg
type	= 0 → composition as mole fraction = 1 → composition as mass fraction
comp	- Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

s_phcomp_HuGas - Specific entropy in kJ/(kg K)

Range of validity:

Temperature t :	$-70\ °C \le t \le 3026.85\ °C$
Pressure p:	$0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

$$\text{s\_phcomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

s_ptcomp_HuGas

Input values:

p	- Pressure p in bar
t	- Temperature t in °C
type	= 0 $\rightarrow$ composition as mole fraction = 1 $\rightarrow$ composition as mass fraction
comp	- Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

s_ptcomp_HuGas - Specific entropy in kJ/(kg K)

Range of validity:

Temperature t :	$-70\ °C \le t \le 3026.85\ °C$
Pressure p:	$0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

$$\text{s\_ptcomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

Surface Tension of Water σ_W = f(t)

Function Name:

Sigmaw_t_HuGas

Input values:

t - Temperature t in °C

Result:

Sigmaw_t_HuGas - Surface tension of water σ_w in N/m

Range of validity:

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

Comments:

Calculation for pure water from IAPWS-IF97

Result for incorrect input values:

$$\mathrm{sigmaw\_t\_HuGas} = -1 \cdot 10^{100}$$

References: [8]

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)

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

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

Result:

t_hscomp_HuGas - Temperature t in °C

Range of validity:

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

Pressure *p*: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

$t\_hscomp\_HuGas = -1 \cdot 10^{100}$

Reference:

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

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

Function Name:

t_phcomp_HuGas

Input values:

p - Pressure p in bar

h - Specific enthalpy h in kJ/kg

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

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

Result:

t_phcomp_HuGas - Temperature in °C

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

$$\text{t\_phcomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

t_pscomp_HuGas

Input values:

p - Pressure p in bar

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

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

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

Result:

t_pscomp_HuGas - Temperature t in °C

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

$$t\_pscomp\_HuGas = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

twdew_pcomp_HuGas

Input values:

p - Pressure p in bar

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

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

Result:

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

Range of validity:

Temperature t : $-70\ °\mathrm{C} \le t \le 3026.85\ °\mathrm{C}$

Pressure p: $0.01\ \mathrm{bar} \le p \le 1000\ \mathrm{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Dew point temperature of water $t_{\mathrm{w,dew}} = t_{\mathrm{s}}(p,p_{\mathrm{d}})$ for $t \ge 0.01\ °\mathrm{C}$

(t_{s} – Saturation temperatureof water in gas mixtures)

$t_{\mathrm{w,dew}} = t_{\mathrm{sub}}(p,p_{\mathrm{d}})$ for $t < 0.01\ °\mathrm{C}$

(t_{sub} – Sublimation temperature of water in gas mixtures)

Result for incorrect input values:

$\mathrm{twdew\_pcomp\_HuGas} = -1 \cdot 10^{100}$

References:

$t_{\mathrm{s}}(p,p_d)$ for $t \ge 0.01\ °\mathrm{C}$ from IAPWS-IF97 [1], [2], [3], [4]

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

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

Function Name:

u_ptcomp_HuGas

Input values:

p	- Pressure *p* in bar
t	- Temperature *t* in °C
type	= 0 → composition as mole fraction = 1 → composition as mass fraction
comp	- Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

u_ptcomp_HuGas - Internal energy in kJ/kg

Range of validity:

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

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

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values:

$$u\_ptcomp\_HuGas = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

v_hscomp_HuGas

Input values:

h - Specific enthalpy h in kJ/kg

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

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

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

Result:

v_hscomp_HuGas - Specific volume in m³/kg

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

$\text{v\_hscomp\_HuGas} = -1 \cdot 10^{100}$

Reference:

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

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

Function Name:

v_phcomp_HuGas

Input values:

p	- Pressure p in bar
h	- Specific enthalpy h in kJ/kg
type	= 0 → composition as mole fraction = 1 → composition as mass fraction
comp	- Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

v_phcomp_HuGas - Specific volume in m³/kg

Range of validity:

Temperature t :	$-70\ °C \le t \le 3026.85\ °C$
Pressure p:	$0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

$$\text{v\_phcomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

v_pscomp_HuGas

Input values:

p	- Pressure *p* in bar
s	- Specific entropy *s* in kJ/(kg K)
type	= 0 → composition as mole fraction = 1 → composition as mass fraction
comp	- Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

v_pscomp_HuGas - Specific volume in m³/kg

Range of validity:

Temperature *t* :	$-70\ °C \le t \le 3026.85\ °C$
Pressure *p*:	$0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

$$v\_pscomp\_HuGas = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

v_ptcomp_HuGas

Input values:

p	- Pressure p in bar
t	- Temperature t in °C
type	= 0 → composition as mole fraction = 1 → composition as mass fraction
comp	- Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

v_ptcomp_HuGas - Specific volume in m³/kg

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values:

$$\text{v\_ptcomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

v_tscomp_HuGas

Input values:

t	- Temperature *t* in °C
s	- Specific entropy *s* in kJ/(kg K)
type	= 0 → composition as mole fraction = 1 → composition as mass fraction
comp	- Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

v_tscomp_HuGas - Specific volume in m³/kg

Range of validity:

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

Pressure *p*: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

$\text{v\_tscomp\_HuGas} = -1 \cdot 10^{100}$

Reference:

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

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

Function Name:

w_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

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

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

Result:

w_ptcomp_HuGas - Isentropic speed of sound in m/s

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

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

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

Result for incorrect input values:

$$\mathrm{w\_ptcomp\_HuGas} = -1 \cdot 10^{100}$$

Reference:

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

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

Function Name:

xw_comp_HuGas

Input values:

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

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

Result:

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

Comments:

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

Result for incorrect input values:

$\text{xw\_comp\_HuGas} = -1 \cdot 10^{100}$

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

Function Name:

Psiwl_ptcomp_HuGas

Input values:

p - Pressure p in bar

t - Temperature t in °C

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

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

Result:

Psiwl_ptcomp_HuGas - Mole fraction of water in kmol/kmol

Range of validity:

Temperature t : $t_\tau(p,\text{comp}) \le t \le t_s(p,p_d)$

(t_s – Saturation temperatureof water in gas mixtures)

Pressure p: $0.01 \text{ bar} \le p \le 1000 \text{ bar}$

Comments:

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

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

with $p_{dsat}(p,t)$ for $t \ge 0.01$ °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:

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

Reference:

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

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

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

Function Name:

Psiwsat_ptcomp_HuGas

Input values:

p	- Pressure p in bar
t	- Temperature t in °C
type	= 0 → composition as mole fraction = 1 → composition as mass fraction
comp	- Vector of composition (Ar, Ne, N_2, O_2, CO, CO_2, H_2O, SO_2)

Result:

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

Range of validity:

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

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Comments:

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

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

Result for incorrect input values:

$\text{Psiwsat\_ptcomp\_HuGas} = -1 \cdot 10^{100}$

Reference:

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

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

3.2 Documentation of the Fortran Source Code of LibHuGas

Thermal Diffusivity *a* = f(*p*,*t*,type,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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 ... \psi_8$ 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 m^2/s

Range of validity:

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

Pressure *p*: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

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

Result for incorrect input values:

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

Reference:

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

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

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 ... \psi_8$ 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 : $-70\ °C \leq t \leq 3026.85\ °C$

Pressure p: $0.01\ \text{bar} \leq p \leq 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

- 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	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

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

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 $\xi_1...\xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1... \psi_8$ 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 : $-70\ °C \le t \le 3026.85\ °C$

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

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

Result for incorrect input values:

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

Reference:

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

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

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

- 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	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

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

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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: $0.01\ \text{bar} \leq p \leq 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

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

Result for incorrect input values:

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

Reference:

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

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

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 : $-70\ °C \leq t \leq 3026.85\ °C$

Pressure p: $0.01\ \text{bar} \leq p \leq 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

- 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	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

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

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 ... \psi_8$ 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 CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

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

Result for incorrect input values:

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

Reference:

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

Dynamic Viscosity η = f(p,t,type,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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 ... \psi_8$ 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 : $-70\ °C \le t \le 3026.85\ °C$

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values:

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

Reference:

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

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

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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* : $-70\ °C \leq t \leq 3026.85\ °C$

Pressure *p*: $0.01\ \text{bar} \leq p \leq 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 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	[26]	[27]	-
Ne	[26]	-	-
N_2	[26]	[28]	-
O_2	[26]	[29]	-
CO	[26]	-	-
CO_2	[26]	[30]	-
H_2O	[26]	[31]	[25]
SO_2	[26]	-	-

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

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 ... \psi_8$ 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* : $-70\ °C \le t \le 3026.85\ °C$

Pressure *p*: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \le \psi_{w,sat}$) 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_pt_HuGas = $-1 \cdot 10^{100}$

Reference:

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

Specific Enthalpy h = f(t,s,type,comp)

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 ... \psi_8$ 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 : $-70\ °C \le t \le 3026.85\ °C$

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \le \psi_{w,sat}$) 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 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	[26]	[27]	-
Ne	[26]	-	-
N_2	[26]	[28]	-
O_2	[26]	[29]	-
CO	[26]	-	-
CO_2	[26]	[30]	-
H_2O	[26]	[31]	[25]
SO_2	[26]	-	-

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

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 : $-70\ °C \le t \le 3026.85\ °C$
Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$
Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

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

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

Reference:

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

Isentropic Exponent κ = f(p,s,type,comp)

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 $\xi_1...\xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1... \psi_8$ 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 ≤ t ≤ 3026.85 °C

Pressure p: 0.01 bar ≤ p ≤ 1000 bar

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

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

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

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

Result for incorrect input values:

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

Reference:

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

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 $\xi_1 \ldots \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 \ldots \psi_8$ 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 : $-70\ ^\circ\text{C} \leq t \leq 3026.85\ ^\circ\text{C}$

Pressure p: $0.01\ \text{bar} \leq p \leq 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Result for incorrect input values:

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

Reference:

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

Molar mass *M* = f(type,comp)

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 = $-1 \cdot 10^{100}$

Kinematic Viscosity υ = f(p,t,type,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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 ... \psi_8$ 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 m^2/s

Range of validity:

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

Pressure p: $0.01\ \text{bar} \leq p \leq 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Result for incorrect input values:

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

Reference:

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

Pressure p = f(h,s,type,comp)

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 : $-70\ °C \le t \le 3026.85\ °C$

Pressure p: $0.01\ \text{bar} \le p \le 16.5 \cdot 10^6\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

- for unsaturated and saturated humid gas ($\psi_w \le \psi_{w,sat}$) 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 higher than 500 °C

Result for incorrect input values:

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

Reference:

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

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

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 CO_2 and SO_2 less than saturation pressures

Comments:

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

Result for incorrect input values:

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

Reference:

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

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

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 :	$-70\ °C \le t \le 3026.85\ °C$
Pressure p:	$0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Comments:

$p_{dsat}(p,t)$ for $t \ge 0.01$ °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:

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

$p_{dsat}(p,t)$ for $T < 273{,}16$ K from IAPWS-92 [24]

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 ... \psi_8$ 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 : $-70\ °C \le t \le 3026.85\ °C$

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

with $p_{dsat}(p,T)$ for $T \ge 273.16\ K$ - Vapour pressure of water in gas mixtures

for $T < 273.16\ K$ - Sublimation pressures of water in gas mixtures

Result for incorrect input values:

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

Reference:

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

$p_{dsat}(p,t)$ for $T < 273{,}16$ K from IAPWS-92 [24]

Prandtl Number *Pr* = f(*p*,*t*,type,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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 : $-70\ °\text{C} \leq t \leq 3026.85\ °\text{C}$
Pressure p: $0.01\ \text{bar} \leq p \leq 1000\ \text{bar}$
Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Result for incorrect input values:

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

Reference:

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

Gas constant *R* = f(type,comp)

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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: [32]

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 = 4 → Ice fog	= 10 → The CO2 in the gas mixture would be partly liquid. Calculation is terminated.
= 5 → Liquid-ice fog at 0.01 °C exactly	= 11 → The SO2 in the gas mixture would be partly liquid. Calculation is terminated.

Range of validity:

Temperature *t* : $-70\ °C \le t \le 3026.85\ °C$
Pressure *p*: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$
Partial pressures of CO_2 and SO_2 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	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Region = f(*p*,*h*,type,comp)

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 = 4 → Ice fog	= 10 → The CO2 in the gas mixture would be partly liquid. Calculation is terminated.
= 5 → Liquid-ice fog at 0.01 °C exactly	= 11 → The SO2 in the gas mixture would be partly liquid. Calculation is terminated.

Range of validity:

Temperature *t* : $-70\ °C \le t \le 3026.85\ °C$
Pressure *p*: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$
Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Result for incorrect input values:

Region_ph_HuGas = 0

Reference:

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

Region = f(*p*,*s*,type,comp)

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 = 4 → Ice fog	= 10 → The CO2 in the gas mixture would be partly liquid. Calculation is terminated.
= 5 → Liquid-ice fog at 0.01 °C exactly	= 11 → The SO2 in the gas mixture would be partly liquid. Calculation is terminated.

Range of validity:

Temperature *t* : $-70\ °C \le t \le 3026.85\ °C$
Pressure *p*: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$
Partial pressures of CO_2 and SO_2 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	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Region = f(*p*,*t*,type,comp)

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 ... \psi_8$ 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 = 4 → Ice fog	= 10 → The CO2 in the gas mixture would be partly liquid. Calculation is terminated.
= 5 → Liquid-ice fog at 0.01 °C exactly	= 11 → The SO2 in the gas mixture would be partly liquid. Calculation is terminated.

Range of validity:

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

Pressure *p*: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \le \psi_{w,sat}$) 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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 = 4 → Ice fog	= 10 → The CO2 in the gas mixture would be partly liquid. Calculation is terminated.
= 5 → Liquid-ice fog at 0.01 °C exactly	= 11 → The SO2 in the gas mixture would be partly liquid. Calculation is terminated.

Range of validity:

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

Pressure *p*: $0.01\ \text{bar} \leq p \leq 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 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	[26]	[27]
Ne	[26]	-
N_2	[26]	[28]
O_2	[26]	[29]
CO	[26]	-
CO_2	[26]	[30]
H_2O	[26]	[31]
SO_2	[26]	-

Density ρ = f(p,t,type,comp)

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 : $-70\ °C \le t \le 3026.85\ °C$

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

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

Reference:

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

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

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 ... \psi_8$ 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 : $-70\ °C \le t \le 3026.85\ °C$

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

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

Reference:

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

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

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 ξ_1...ξ_8 in kg/kg when TYPE=1
- composition as mole fraction ψ_1... ψ_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 °C $\le$ t $\le$ 3026.85 °C

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

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

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

Reference:

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

Surface Tension of Water $\sigma_w = f(t, type, comp)$

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 : $0\ °C \leq t \leq 373.946\ °C$

Comments:

Calculation for pure water from IAPWS-IF97

Result for incorrect input values:

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

Reference: [8]

Temperature *t* = f(*h*,*s*,type,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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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* : $-70\ °C \le t \le 3026.85\ °C$

Pressure *p*: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

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

Reference:

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

Temperature t = f(p,h,type,comp)

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 $\xi_1 ... \xi_{10}$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_{10}$ 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: $0.01\ \text{bar} \leq p \leq 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Iteration of t 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:

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

Reference:

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

Temperature t = f(p,s,type,comp)

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 : $-70\ °C \le t \le 3026.85\ °C$

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

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

Reference:

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

Dew Point Temperature of Water $T_{\mathrm{w,dew}}$ = f(p,type,comp)

Name in Fortran:

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

Input values:

P - Pressure p in bar

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

Result:

twdew_p_HuGas - Dew point temperature of water $T_{w,\mathrm{dew}}$ in °C

Range of validity:

Pressure p: $0.01 \text{ bar} \leq p \leq 1000 \text{ bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Dew point temperature of water $T_{\mathrm{w,dew}} = T_{\mathrm{s}}(p, p_{\mathrm{d}})$ for $T \geq 273.16$ K
(t_{S} – Boiling temperature of water in gas mixtures)
$T_{\mathrm{w,dew}} = T_{\mathrm{sub}}(p, p_{\mathrm{d}})$ for $T < 273.16$ K
(t_{sub} – Sublimation temperature of water in gas mixtures)

Result for incorrect input values:

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

Reference:

$T_{\mathrm{S}}(p, p_{\mathrm{d}})$ for $T \geq 273.16$ K from IAPWS-IF97 [1], [2], [3], [4]

$T_{\mathrm{sub}}(p, p_{\mathrm{d}})$ for $T < 273.16$ K from IAPWS-92 [24]

Specific Internal Energy *u* = f(*p*,*t*,type,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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 °C $\leq$ t $\leq$ 3026.85 °C
Pressure *p*: 0.01 bar $\leq$ p $\leq$ 1000 bar
Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) as ideal mixture of real fluids
- for fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water or water ice
- 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	[26]	[27]	-
Ne	[26]	-	-
N_2	[26]	[28]	-
O_2	[26]	[29]	-
CO	[26]	-	-
CO_2	[26]	[30]	-
H_2O	[26]	[31]	[25]
SO_2	[26]	-	-

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

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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* : $- 70\ °C \le t \le 3026.85\ °C$

Pressure *p*: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

$v\_hs\_HuGas = -1 \cdot 10^{100}$

Reference:

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

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

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 °C $\leq$ *t* $\leq$ 3026.85 °C

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

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Result for incorrect input values:

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

Reference:

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

Specific Volume v = f(p,s,type,comp)

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 $\xi_1...\xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1... \psi_8$ 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: $0.01\ \text{bar} \leq p \leq 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Result for incorrect input values:

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

Reference:

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

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

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 : $-70\ °C \le t \le 3026.85\ °C$

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values:

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

Reference:

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

Specific Volume v = f(t,s,type,comp)

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 : $-70\ °C \le t \le 3026.85\ °C$

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

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

Reference:

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

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

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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 ≤ *t* ≤ 3026.85 °C
Pressure *p*: 0.01 bar ≤ *p* ≤ 1000 bar
Partial pressures of CO_2 and SO_2 less than saturation pressures

Comments:

Calculation:

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

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

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

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

Result for incorrect input values:

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

Reference:

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

Humidity Ratio (Absolute Humidity) x_W = f(type,comp)

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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1 ... \psi_8$ 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:

Humidity ratio of water $x_\mathrm{w} = \dfrac{\psi_\mathrm{w}}{\dfrac{R_\mathrm{w}}{R_\mathrm{mix}} - \psi_\mathrm{w}}$

Result for incorrect input values:

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

Mole Fraction of Liquid Water ψ_{wl} = f(p,t,type,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 $\xi_1...\xi_8$ in kg/kg when TYPE=1
- composition as mole fraction $\psi_1... \psi_8$ 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_τ (p,type,comp) $\leq$ 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 liquid water: $\psi_{wl} = \psi_w - \psi_{wsat}$

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

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

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

Result for incorrect input values:

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

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 [24]

Mole Fraction of Water of Saturated Gas $\psi_{w,sat}$ = f(p,t,type,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 $\xi_1 ... \xi_8$ in kg/kg when TYPE=1

- composition as mole fraction $\psi_1 ... \psi_8$ 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 : $-70\ °C \le t \le T_s(p,p_d)$

(t_s – Boiling temperature of water in gas mixtures)

Pressure p: $0.01\ \text{bar} \le p \le 1000\ \text{bar}$

Comments:

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

with $p_{dsat}(p,t)$ for $t \ge 0.01$ °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 = $-1 \cdot 10^{100}$

Reference:

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

$p_{dsat}(p,t)$ for $T < 273{,}16$ K from IAPWS-92 [24]

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

Water and Steam

Library LibIF97

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

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:

CO_2 - Span and Wagner
H_2O - IAPWS-95
N_2 - Span et al.
O_2 - Schmidt and Wagner
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 and Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:

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

Consideration of:

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

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

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

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture
from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Humid Air

Library ASHRAE LibHuAirProp

Model: Virial Equation from ASHRAE Report RP-1485 for real mixture of the real fluids:

- Dry air
- Steam

Consideration of:

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

www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of
Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of
Bücker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of
Bücker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

Helmholtz energy equation for the mixing term

(also useable for calculating Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

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

Formulation of the International Institute of Refrigeration (1997)

Ethanol

Library LibC2H5OH

Formulation of Schroeder (2012)

Methanol

Library LibCH3OH

Formulation of de Reuck and Craven (1993)

Propane

Library LibPropane

Formulation of Lemmon et al. (2009)

Siloxanes as ORC Working Fluids

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

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

Tetradecamethylhexasiloxane $C_{14}H_{42}O_5Si_6$ **Library LibMD4M**

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Nitrogen

Library LibN2

Formulation of Span et al. (2000)

Hydrogen

Library LibH2

Formulation of Leachman et al. (2009)

Helium

Library LibHe

Formulation of Arp et al. (1998)

Hydrocarbons

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

Isopentane C_5H_{12} **Library LibC5H12_ISO**

Neopentane C_5H_{12} **Library LibC5H12_NEO**

Isohexane C_6H_{14} **Library LibC6H14**

Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

Carbon monoxide CO **Library LibCO**

Carbonyl sulfide COS **Library LibCOS**

Hydrogen sulfide H_2S **Library LibH2S**

Dinitrogen monooxide N_2O **Library LibN2O**

Sulfur dioxide SO_2 **Library LibSO2**

Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

For more information please contact:

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Dr. Ines Stoecker

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Fax.: +49-3583-61-1846

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

---

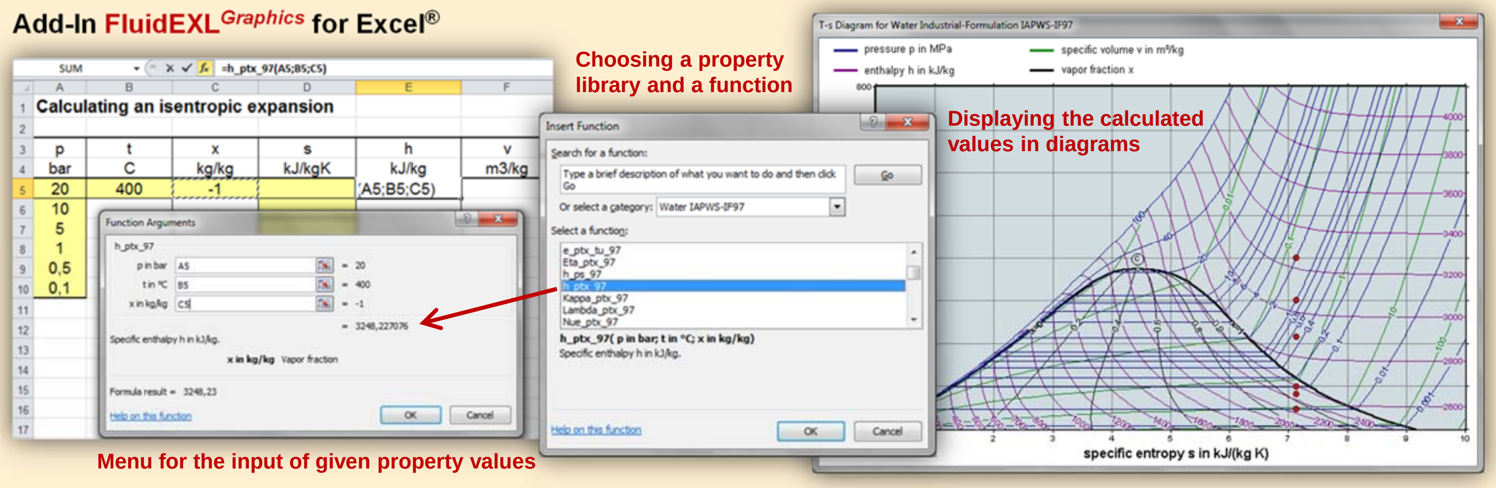
[a] Not all of these property functions are available in all property libraries.

www.thermodynamic-property-libraries.com

ZITTAU/GOERLITZ UNIVERSITY OF APPLIED SCIENCES
Department of Technical Thermodynamics
www.thermodynamics-zittau.de

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

Add-In FluidEXL*Graphics* for Excel®



Calculating an isentropic expansion

p	t	x	s	h	v
bar	C	kg/kg	kJ/kgK	kJ/kg	m3/kg
20	400	-1		A5;B5;C5)	
10					
5					
1					
0,5					
0,1					

=h_ptx_97(A5;B5;C5)

h_ptx_97(p in bar; t in °C; x in kg/kg)
Specific enthalpy h in kJ/kg.

Formula result = 3248,23

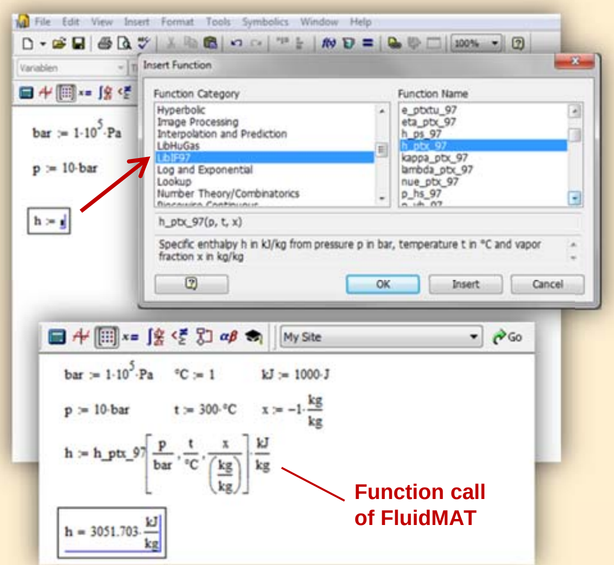
Choosing a property library and a function

Displaying the calculated values in diagrams

Menu for the input of given property values

Add-In FluidMAT for Mathcad®

The property libraries can be used in Mathcad®.



$bar := 1\cdot 10^5\cdot Pa \quad °C := 1 \quad kJ := 1000\cdot J$

$p := 10\cdot bar \quad t := 300\cdot °C \quad x := -1\cdot \frac{kg}{kg}$

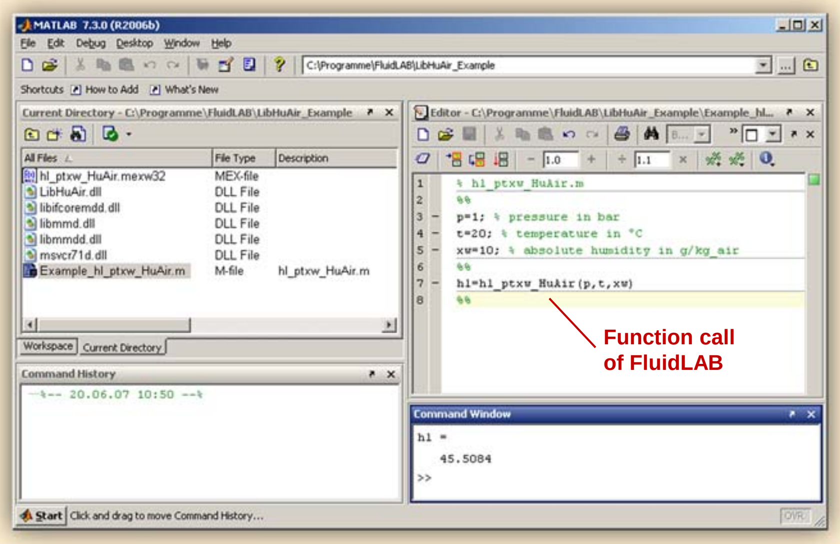
$h := h\_ptx\_97\left(\frac{p}{bar}, \frac{t}{°C}, \frac{x}{\left(\frac{kg}{kg}\right)}\right)\cdot\frac{kJ}{kg}$

$h = 3051.703\cdot\frac{kJ}{kg}$

Function call of FluidMAT

Add-In FluidLAB for MATLAB®

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



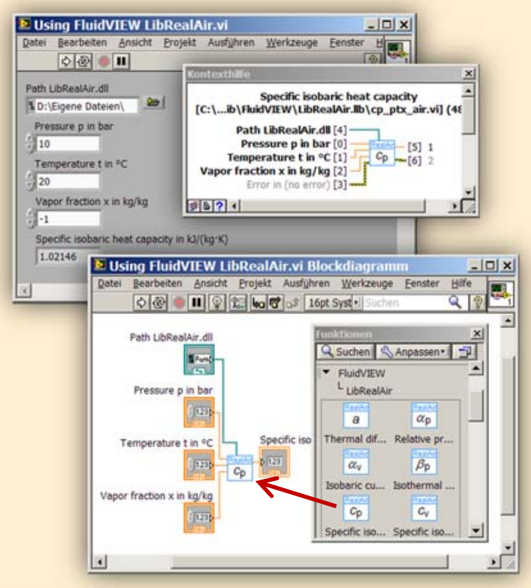
```
% hl_ptxw_HuAir.m
%%
p=1; % pressure in bar
t=20; % temperature in °C
xw=10; % absolute humidity in g/kg_air
%%
hl=hl_ptxw_HuAir(p,t,xw)
%%
```

```
hl =

   45.5084

>>
```

Function call of FluidLAB

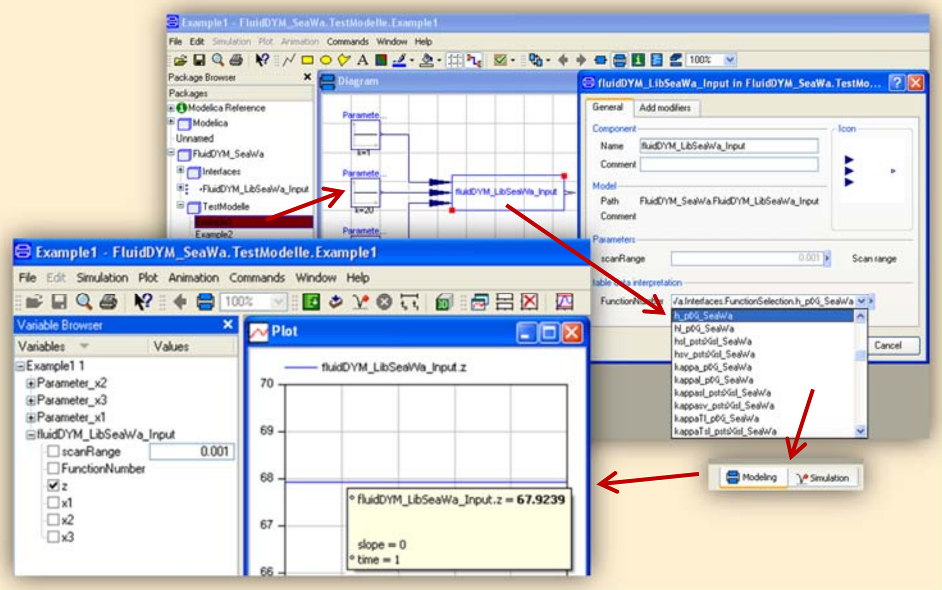
Add-On FluidVIEW for LabVIEW®

The property functions can be calculated in LabVIEW®.



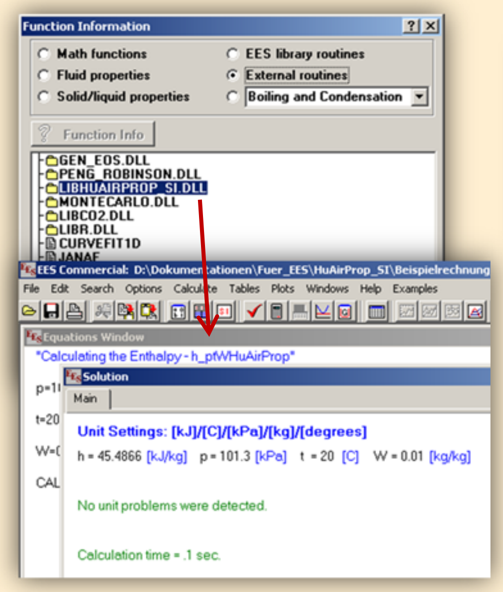
Add-In FluidDYM for DYMOLA® (Modelica) and SimulationX®

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



fluidDYM_LibSeaWa_Input.z = 67.9239

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



"Calculating the Enthalpy - h_ptWHuAirProp"

p=1

t=20

W=(

CAL

Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]

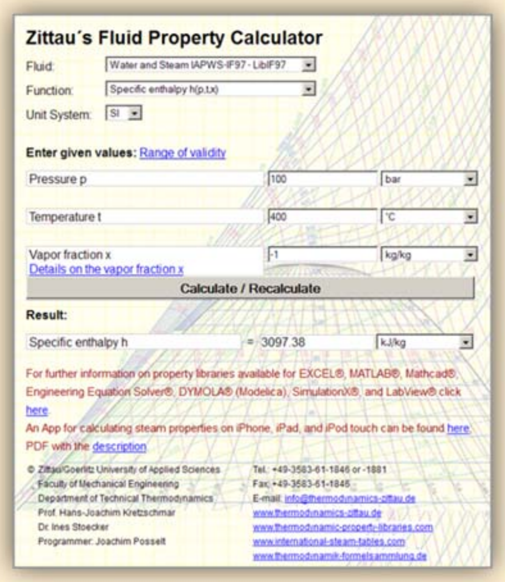
h = 45.4866 [kJ/kg]   p = 101.3 [kPa]   t = 20 [C]   W = 0.01 [kg/kg]

No unit problems were detected.

Calculation time = .1 sec.

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

Online Property Calculator at www.thermodynamics-zittau.de



Fluid: Water and Steam IAPWS-IF97 - LibIF97

Function: Specific enthalpy h(p,t,x)

Unit System: SI

Enter given values: Range of validity

Pressure p: 100 bar

Temperature t: 400 °C

Vapor fraction x: -1 kg/kg

Details on the vapor fraction x

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

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www.thermodynamic-property-libraries.com
www.international-steam-tables.com
www.thermodynamik-formelsammlung.de

Property Software for Pocket Calculators

FluidCasio

fx 9750 G II

CFX 9850
fx-GG20

CFX 9860 G
Graph 85

ALGEBRA
FX 2.0

FluidHP

HP 48

HP 49

FluidTI

TI Nspire CX CAS
TI Nspire CAS

TI 83
TI 84
TI 89

TI 92

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

---

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

www.thermodynamic-property-libraries.com

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6. Satisfied Customers

Date: 04/2014

The following companies and institutions use the property libraries

- FluidEXL$^{\mathit{Graphics}}$ for Excel®
- FluidLAB for MATLAB®
- FluidMAT for Mathcad®
- FluidEES for Engineering Equation Solver® EES
- FluidDYM for Dymola® (Modelica) and SimulationX®
- FluidVIEW for LabVIEW®:

2014

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MTU Aero Engines AG, Munich	04/2014
GKS, Schweinfurt	03/2014
Technical University of Nurnberg	03/2014
EP-E, Niederstetten	03/2014
Rückert NatUrgas GmbH, Lauf	03/2014
YESS-World, South Korea	03/2014
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COMPAREX, Leipzig for RWE Essen	02/2014
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Technical University of Munich	01/2014
Technical University of Braunschweig	01/2014
M&M Turbinentechnik, Bielefeld	01/2014

2013

TRANTER-GmbH, Artern	12/2013
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VOITH, Kunshan, China	12/2013
ULT, Löbau	12/2013
MAN, Copenhagen, Dänemark	11/2013
DREWAG, Dresden	11/2013
Haarslev Industries, Herlev, Dänemark	11/2013
STEAG, Herne	11/2013, 12/2013
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for RWE Essen	12/2013
University of Budapest, Hungary	08/2013
Siemens, Frankenthal	08/2013, 10/2013 11/2013
VGB, Essen	07/2013, 11/2013
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Technician School of Berlin	05/2013
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Schwing/Stetter GmbH, Memmingen	05/2013
Vattenfall, Berlin	05/2013
AUTARK, Kleinmachnow	05/2013
STEAG, Zwingenberg	05/2013
Hochtief, Düsseldorf	05/2013
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Rerum Cognitio Forschungszentrum, Frankfurt	04/2013
Kältetechnik Dresen + Bremen, Alfhausen	04/2013
University Auckland, New Zealand	04/2013
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Technical University of Wismar	02/2013
Technical University of Dusseldorf	02/2013
ILK, Dresden	01/2013, 08/2013
Fichtner IT, Stuttgart	01/2013, 11/2013
Schnepf Ingeniuerbüro, Nagold	01/2013
Schütz Engineering, Wadgassen	01/2013
Endress & Hauser, Reinach, Switzerland	01/2013
Oschatz GmbH, Essen	01/2013
frischli Milchwerke, Rehburg-Loccum	01/2013

2012

Voith, Bayreuth	12/2012
Technical University of Munich	12/2012
Dillinger Huette	12/2012
University of Stuttgart	11/2012
Siemens, Muehlheim	11/2012
Sennheiser, Hannover	11/2012
Oschatz GmbH, Essen	10/2012
Fichtner IT, Stuttgart	10/2012, 11/2012
Helbling Technik AG, Zurich, Switzerland	10/2012
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Rerum Cognitio Forschungszentrum, Frankfurt	09/2012
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BASF, Ludwigshafen (general license) via Fichtner IT Consult	05/2012
SPX Balcke-Dürr, Ratingen	05/2012, 07/2012
Gruber-Schmidt, Wien, Austria	04/2012
Vattenfall, Berlin	04/2012
ALSTOM, Baden	04/2012
SKW, Piesteritz	04/2012
TERA Ingegneria, Trento, Italy	04/2012
Siemens, Erlangen	04/2012, 05/2012
LAWI Power, Dresden	04/2012
Stadtwerke Leipzig	04/2012
SEITZ, Wetzikon, Switzerland	03/2012, 07/2012
M & M, Bielefeld	03/2012
Sennheiser, Wedemark	03/2012

SPG, Montreuil Cedex, France	02/2012
German Destilation, Sprendlingen	02/2012
Lopez, Munguia, Spain	02/2012
Endress & Hauser, Hannover	02/2012
Palo Alto Research Center, USA	02/2012
WIPAK, Walsrode	02/2012
Freudenberg, Weinheim	01/2012
Fichtner, Stuttgart	01/2012
airinotec, Bayreuth	01/2012, 07/2012
University Auckland, New Zealand	01/2012
VPC, Vetschau	01/2012
Franken Guss, Kitzingen	01/2012

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XRG-Simulation, Hamburg	12/2011
Smurfit Kappa PPT, AX Roermond, Netherlands	12/2011
AWTEC, Zurich, Switzerland	12/2011
eins-energie, Bad Elster	12/2011
BeNow, Rodenbach	11/2011
Luzern University of Applied Sciences, Switzerland	11/2011
GMVA, Oberhausen	11/2011
CCI, Karlsruhe	10/2011
W.-Büchner University of Applied Sciences, Pfungstadt	10/2011
PLANAIR, La Sagne, Switzerland	10/2011
LAWI, Dresden	10/2011
Lopez, Munguia, Spain	10/2011
University of KwaZulu-Natal, Westville, South Africa	10/2011
Voith, Heidenheim	09/2011
SpgBe Montreal, Canada	09/2011
SPG TECH, Montreuil Cedex, France	09/2011
Voith, Heidenheim-Mergelstetten	09/2011
MTU Aero Engines, Munich	08/2011
MIBRAG, Zeitz	08/2011
RWE, Essen	07/2011
Fels, Elingerode	07/2011

Weihenstephan University of Applied Sciences	07/2011, 09/2011 10/2011
Forschungszentrum Juelich	07/2011
RWTH Aachen University	07/2011, 08/2011
INNEO Solutions, Ellwangen	06/2011
Caliqua, Basel, Switzerland	06/2011
Technical University of Freiberg	06/2011
Fichtner IT Consulting, Stuttgart	05/2011, 06/2011, 08/2011
Salzgitter Flachstahl, Salzgitter	05/2011
Helbling Beratung & Bauplanung, Zurich, Switzerland	05/2011
INEOS, Cologne	04/2011
Enseleit Consulting Engineers, Siebigerode	04/2011
Witt Consulting Engineers, Stade	03/2011
Helbling, Zurich, Switzerland	03/2011
MAN Diesel, Copenhagen, Denmark	03/2011
AGO, Kulmbach	03/2011
University of Duisburg	03/2011, 06/2011
CCP, Marburg	03/2011
BASF, Ludwigshafen	02/2011
ALSTOM Power, Baden, Switzerland	02/2011
Universität der Bundeswehr, Munich	02/2011
Calorifer, Elgg, Switzerland	01/2011
STRABAG, Vienna, Austria	01/2011
TUEV Sued, Munich	01/2011
ILK Dresden	01/2011
Technical University of Dresden	01/2011, 05/2011 06/2011, 08/2011

2010

Umweltinstitut Neumarkt	12/2010
YIT Austria, Vienna, Austria	12/2010
MCI Innsbruck, Austria	12/2010
University of Stuttgart	12/2010
HS Cooler, Wittenburg	12/2010
Visteon, Novi Jicin, Czech Republic	12/2010
CompuWave, Brunntal	12/2010

Stadtwerke Leipzig	12/2010
MCI Innsbruck, Austria	12/2010
EVONIK Energy Services, Zwingenberg	12/2010
Caliqua, Basel, Switzerland	11/2010
Shanghai New Energy Resources Science & Technology, China	11/2010
Energieversorgung Halle	11/2010
Hochschule für Technik Stuttgart, University of Applied Sciences	11/2010
Steinmueller, Berlin	11/2010
Amberg-Weiden University of Applied Sciences	11/2010
AREVA NP, Erlangen	10/2010
MAN Diesel, Augsburg	10/2010
KRONES, Neutraubling	10/2010
Vaillant, Remscheid	10/2010
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Schubert Consulting Engineers, Weißenberg	10/2010
Fraunhofer Institut UMSICHT, Oberhausen	10/2010
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Siemens Energy, Nuremberg	02/2010
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ALSTOM Power, Baden, Schweiz	01/2009, 03/2009 05/2009
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CPP, Marburg	03/2009
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Institute of Air Handling and Refrigeration ILK, Dresden	11/2009
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Techgroup, Ratingen	11/2009
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EC, Heidelberg	11/2009
MCI, Innsbruck, Austria	12/2009
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ENERKO, Aldenhoven	12/2009

2008

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RWE IT, Essen	04/2008
Rerum Cognitio, Zwickau	04/2008, 05/2008
ARUP, Berlin	05/2008
Research Center, Karlsruhe	07/2008
AWECO, Neukirch	07/2008
Technical University of Dresden, Professorship of Building Services	07/2008
Technical University of Cottbus, Chair in Power Plant Engineering	07/2008, 10/2008
Ingersoll-Rand, Unicov, Czech Republic	08/2008
Technip Benelux BV, Zoetermeer, Netherlands	08/2008
Fennovoima Oy, Helsinki, Finland	08/2008
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PEU, Espenhain	09/2008
Poyry, Dresden	09/2008
WINGAS, Kassel	09/2008
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Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	10/2008, 11/2008
AWTEC, Zurich, Switzerland	11/2008
Siemens Power Generation, Erlangen	12/2008

2007

Audi, Ingolstadt	02/2007
ANO Abfallbehandlung Nord, Bremen	02/2007
TUEV NORD SysTec, Hamburg	02/2007
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Redacom, Nidau, Switzerland	02/2007
Universität der Bundeswehr, Munich	02/2007
Maxxtec, Sinsheim	03/2007
University of Rostock, Chair in Technical Thermodynamics	03/2007
AGO, Kulmbach	03/2007
University of Stuttgart, Chair in Aviation Propulsions	03/2007
Siemens Power Generation, Duisburg	03/2007

ENTHAL Haustechnik, Rees	05/2007
AWECO, Neukirch	05/2007
ALSTOM, Rugby, Great Britain	06/2007
SAAS, Possendorf	06/2007
Grenzebach BSH, Bad Hersfeld	06/2007
Reichel Engineering, Haan	06/2007
Technical University of Cottbus, Chair in Power Plant Engineering	06/2007
Voith Paper Air Systems, Bayreuth	06/2007
Egger Holzwerkstoffe, Wismar	06/2007
Tissue Europe Technologie, Mannheim	06/2007
Dometic, Siegen	07/2007
RWTH Aachen University, Institute for Electrophysics	09/2007
National Energy Technology Laboratory, Pittsburg, USA	10/2007
Energieversorgung Halle	10/2007
AL-KO, Jettingen	10/2007
Grenzebach BSH, Bad Hersfeld	10/2007
Wiesbaden University of Applied Sciences, Department of Engineering Sciences	10/2007
Endress+Hauser Messtechnik, Hannover	11/2007
Munich University of Applied Sciences, Department of Mechanical Engineering	11/2007
Rerum Cognitio, Zwickau	12/2007
Siemens Power Generation, Erlangen	11/2007
University of Rostock, Chair in Technical Thermodynamics	11/2007, 12/2007

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Technical University of Munich, Chair in Energy Systems	01/2006
NUTEC Engineering, Bisikon, Switzerland	01/2006, 04/2006
Conwel eco, Bochov, Czech Republic	01/2006
Offenburg University of Applied Sciences	01/2006
KOCH Transporttechnik, Wadgassen	01/2006
BEG Bremerhavener Entsorgungsgesellschaft	02/2006
Deggendorf University of Applied Sciences, Department of Mechanical Engineering and Mechatronics	02/2006
University of Stuttgart, Department of Thermal Fluid Flow Engines	02/2006

Technical University of Munich, Chair in Apparatus and Plant Engineering	02/2006
Energietechnik Leipzig (company license),	02/2006
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RWE Power, Essen	03/2006
WAETAS, Pobershau	04/2006
Siemens Power Generation, Goerlitz	04/2006
Technical University of Braunschweig, Department of Thermodynamics	04/2006
EnviCon & Plant Engineering, Nuremberg	04/2006
Brassel Engineering, Dresden	05/2006
University of Halle-Merseburg, Department of USET Merseburg incorporated society	05/2006
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Siemens Power Generation, Duisburg	10/2006
Hannover University of Applied Sciences, Department of Mechanical Engineering	10/2006
Siemens Power Generation, Berlin	11/2006
Zikesch Armaturentechnik, Essen	11/2006
Wismar University of Applied Sciences, Seafaring Department	11/2006
BASF, Schwarzheide	12/2006
Enertech Energie und Technik, Radebeul	12/2006

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TUEV Nord, Hannover	01/2005
J.H.K Plant Engineering and Service, Bremerhaven	01/2005
Electrowatt-EKONO, Zurich, Switzerland	01/2005

FCIT, Stuttgart	01/2005
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eta Energieberatung, Pfaffenhofen	02/2005
FZR Forschungszentrum, Rossendorf/Dresden	04/2005
University of Saarbruecken	04/2005
Technical University of Dresden Professorship of Thermic Energy Machines and Plants	04/2005
Grenzebach BSH, Bad Hersfeld	04/2005
TUEV Nord, Hamburg	04/2005
Technical University of Dresden, Waste Management	05/2005
Siemens Power Generation, Goerlitz	05/2005
Duesseldorf University of Applied Sciences, Department of Mechanical Engineering and Process Engineering	05/2005
Redacom, Nidau, Switzerland	06/2005
Dumas Verfahrenstechnik, Hofheim	06/2005
Alensys Engineering, Erkner	07/2005
Stadtwerke Leipzig	07/2005
SaarEnergie, Saarbruecken	07/2005
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Technical University of Berlin	10/2005
Basel University of Applied Sciences, Department of Mechanical Engineering, Switzerland	10/2005
Midiplan, Bietigheim-Bissingen	11/2005
Technical University of Freiberg, Chair in Hydrogeology	11/2005
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MAN B&W Diesel A/S, Copenhagen, Denmark	02/2004
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Ulm University of Applied Sciences	03/2004
Visteon, Kerpen	03/2004, 10/2004
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	04/2004
Rerum Cognitio, Zwickau	04/2004
University of Saarbruecken	04/2004
Grenzebach BSH, Bad Hersfeld	04/2004
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HEW-Kraftwerk, Tiefstack	06/2004
h s energieanlagen, Freising	07/2004
FCIT, Stuttgart	08/2004
Physikalisch Technische Bundesanstalt (PTB), Braunschweig	08/2004
Mainova Frankfurt	08/2004
Rietschle Energieplaner, Winterthur, Switzerland	08/2004
MAN Turbo Machines, Oberhausen	09/2004
TUEV Sued, Dresden	10/2004
STEAG Kraftwerk, Herne	10/2004, 12/2004
University of Weimar	10/2004
energeticals (e-concept), Munich	11/2004
SorTech, Halle	11/2004
Enertech EUT, Radebeul (company license)	11/2004
Munich University of Applied Sciences	12/2004
STORA ENSO Sachsen, Eilenburg	12/2004
Technical University of Cottbus, Chair in Power Plant Engineering	12/2004
Freudenberg Service, Weinheim	12/2004

2003

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

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

2002

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

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

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

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

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