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Property Software for the Calculation of Humid Combustion Gases

FluidLAB
LibHuFlueGas
for MATLAB®

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Property Software for Humid Gas Combustion in FluidLAB LibHuFlueGas

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0 Package Contents

CD "FluidLAB including LibHuFlueGas for MATLAB®"

Property Functions of Humid Combustion Gas Mixtures

Calculated as Ideal Mixture of Real Fluids in the "LibHuFlueGas Library"

Including the following files:

LibHuFlueGas.dll	Dynamic Link Library for Humid Combustion Gas Mixtures calculated as Ideal Mixture of Real Fluids for use in MATLAB®
Docu_FluidLAB_LibHuFlueGas_Eng.pdf	User's Guide

There are according MATLAB®-extensions for every calculable function as well, which you can find below:

a_pTcomp_HuFlueGas.mexw32	R_comp_HuFlueGas.mexw32
cp_hscomp_HuFlueGas.mexw32	Region_hscomp_HuFlueGas.mexw32
cp_phcomp_HuFlueGas.mexw32	Region_phcomp_HuFlueGas.mexw32
cp_pscomp_HuFlueGas.mexw32	Region_pscomp_HuFlueGas.mexw32
cp_pTcomp_HuFlueGas.mexw32	Region_pTcomp_HuFlueGas.mexw32
cp_Tscomp_HuFlueGas.mexw32	Region_Tscomp_HuFlueGas.mexw32
cv_pTcomp_HuFlueGas.mexw32	rho_pTcomp_HuFlueGas.mexw32
eta_pTcomp_HuFlueGas.mexw32	s_phcomp_HuFlueGas.mexw32
h_pscomp_HuFlueGas.mexw32	s_pTcomp_HuFlueGas.mexw32
h_pTcomp_HuFlueGas.mexw32	sigmaw_T_HuFlueGas.mexw32
h_Tscomp_HuFlueGas.mexw32	T_hscomp_HuFlueGas.mexw32
kappa_pscomp_HuFlueGas.mexw32	T_phcomp_HuFlueGas.mexw32
kappa_pTcomp_HuFlueGas.mexw32	T_pscomp_HuFlueGas.mexw32
lambda_pTcomp_HuFlueGas.mexw32	Tw dew_pcomp_HuFlueGas.mexw32
M_comp_HuFlueGas.mexw32	u_pTcomp_HuFlueGas.mexw32
nue_pTcomp_HuFlueGas.mexw32	v_hscomp_HuFlueGas.mexw32
p_hscomp_HuFlueGas.mexw32	v_phcomp_HuFlueGas.mexw32
p_Tscomp_HuFlueGas.mexw32	v_pscomp_HuFlueGas.mexw32
pdsat_pT_HuFlueGas.mexw32	v_pTcomp_HuFlueGas.mexw32
phi_pTcomp_HuFlueGas.mexw32	v_Tscomp_HuFlueGas.mexw32
Pr_pTcomp_HuFlueGas.mexw32	w_pTcomp_HuFlueGas.mexw32
psiwl_pTcomp_HuFlueGas.mexw32	xw_comp_HuFlueGas.mexw32
psiwsat_pTcomp_HuFlueGas.mexw32	

User's Guide as printed copy in case of shipment

1 Calculation Programs

Functional Dependence	Function Name in FluidLAB	Property or Function	Unit of calculated value
Set_comp_mass		Input of the composition as mass fractions	-
Set_comp_mol		Input of the composition as mole fractions	-
Get_comp_mass		Output of the current composition as mass	-
Get_comp_mol		Output of the current composition as mole	-
$a = f(p, T)$	a_pTcomp_HuFlueGas	Temperature diffusivity	m^2/s
$c_p = f(h, s)$	cp_hscomp_HuFlueGas	Backward function: isobaric heat capacity from enthalpy and entropy	$\text{kJ}/(\text{kg} \cdot \text{K})$
$c_p = f(p, h)$	cp_phcomp_HuFlueGas	Backward function: isobaric heat capacity from pressure and enthalpy	$\text{kJ}/(\text{kg} \cdot \text{K})$
$c_p = f(p, s)$	cp_pscmp_HuFlueGas	Backward function: isobaric heat capacity from pressure and entropy	$\text{kJ}/(\text{kg} \cdot \text{K})$
$c_p = f(p, T)$	cp_pTcomp_HuFlueGas	Isobaric heat capacity	$\text{kJ}/(\text{kg} \cdot \text{K})$
$c_p = f(T, s)$	cp_Tscomp_HuFlueGas	Backward function: isobaric heat capacity from temperature and entropy	$\text{kJ}/(\text{kg} \cdot \text{K})$
$c_v = f(p, T)$	cv_pTcomp_HuFlueGas	Isochoric heat capacity	$\text{kJ}/(\text{kg} \cdot \text{K})$
$\eta = f(p, T)$	eta_pTcomp_HuFlueGas	Dynamic viscosity	$\text{Pa} \cdot \text{s}$
$h = f(p, s)$	h_pscmp_HuFlueGas	Backward function: enthalpy from pressure and entropy	kJ/kg
$h = f(p, T)$	h_pTcomp_HuFlueGas	Enthalpy	kJ/kg
$h = f(T, s)$	h_Tscomp_HuFlueGas	Backward function: enthalpy from temperature and entropy	kJ/kg
$\kappa = f(p, s)$	kappa_pscmp_HuFlueGas	Backward function: isentropic exponent from pressure and entropy	-
$\kappa = f(p, T)$	kappa_pTcomp_HuFlueGas	Isentropic exponent	-
$\lambda = f(p, T)$	lambda_pTcomp_HuFlueGas	Thermal conductivity	$\text{W}/(\text{m} \cdot \text{K})$
M	M_comp_HuFlueGas	Molar mass	kg/mol
$\nu = f(p, T)$	nue_pTcomp_HuFlueGas	Kinematic viscosity	m^2/s

$p = f(h,s)$	p_hscomp_HuFlueGas	Backward function: pressure from enthalpy and entropy	bar
$p = f(T,s)$	p_Tscomp_HuFlueGas	Backward function: pressure from temperature and entropy	bar
$p_{\text{dsat}} = f(p,T)$	pdsat_pTcomp_HuFlueGas	Saturation pressure of water in mixture	bar
$\varphi = f(p,T)$	phi_pTcomp_HuFlueGas	Relative humidity	%
$Pr = f(p,T)$	Pr_pTcomp_HuFlueGas	Prandtl number	-
$\psi_{\text{wl}} = f(p,T)$	psiwl_pTcomp_HuFlueGas	Mole fraction of water (liquid)	kmol/kmol
$\psi_{\text{wsat}} = f(p,T)$	psiwsat_pTcomp_HuFlueGas	Mole fraction of water of the saturated gas	kmol/kmol
R	R_comp_HuFlueGas	Gas constant	kJ/(kg · K)
$\text{Region} = f(h,s)$	Region_hscomp_HuFlueGas	Region from given enthalpy and entropy	-
$\text{Region} = f(p,h)$	Region_phcomp_HuFlueGas	Region from given pressure and enthalpy	-
$\text{Region} = f(p,s)$	Region_pscomp_HuFlueGas	Region from given pressure and entropy	-
$\text{Region} = f(p,T)$	Region_pTcomp_HuFlueGas	Region from given pressure and temperature	-
$\text{Region} = f(T,s)$	Region_Tscomp_HuFlueGas	Region from given temperature and entropy	-
$\rho = f(p,T)$	rho_pTcomp_HuFlueGas	Density	kg/m ³
$s = f(p,h)$	s_phcomp_HuFlueGas	Backward function: entropy from pressure and enthalpy	kJ/(kg · K)
$s = f(p,T)$	s_pTcomp_HuFlueGas	Entropy	kJ/(kg · K)
$\sigma_{\text{w}} = f(T)$	sigmaw_T_HuFlueGas	Surface tension of water	N/m
$T = f(h,s)$	T_hscomp_HuFlueGas	Backward function: temperature from enthalpy and entropy	°C
$T = f(p,h)$	T_phcomp_HuFlueGas	Backward function: temperature from pressure and enthalpy	°C
$T = f(p,s)$	T_pscomp_HuFlueGas	Backward function: temperature from pressure and entropy	°C

$T_{w,dew} = f(p)$	Twdew_pcomp_HuFlueGas	Dew point temperature of water	°C
$u = f(p,T)$	u_pTcomp_HuFlueGas	Internal energy	kJ/kg
$v = f(h,s)$	v_hscomp_HuFlueGas	Backward function: specific volume from enthalpy and entropy	m ³ /kg
$v = f(p,h)$	v_phcomp_HuFlueGas	Backward function: specific volume from pressure and enthalpy	m ³ /kg
$v = f(p,s)$	v_pscomp_HuFlueGas	Backward function: specific volume from pressure and entropy	m ³ /kg
$v = f(p,T)$	v_pTcomp_HuFlueGas	Specific volume	m ³ /kg
$v = f(T,s)$	v_Tscomp_HuFlueGas	Backward function: specific volume from temperature and entropy	m ³ /kg
$w = f(p,T)$	w_pTcomp_HuFlueGas	Isentropic speed of sound	m/s
x_w	xw_comp_HuFlueGas	Absolute humidity	kg/kg _{Gas}

Units:

- p - Pressure p of mixture in bar
- T - Temperature T in °C
- type - Type of composition:
 - type = 0 for composition as mole fractions ψ in mol/mol
 - type = 1 for composition as mass fractions ξ in g/g
- comp(1:8) - Mole or mass fractions of components

Parameter for using Fortran Functions of LibHuFlueGas

- 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_HUFLUEGAS.

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

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_HUFLUEGAS or SET_COMP_MASS_HUFLUEGAS again.

In order to know which composition is stored it can be called by using GET_COMP_MASS_HUFLUEGAS or GET_COMP_MOL_HUFLUEGAS.

Range of Validity:

Humid gas mixture

Temperature: $T = -70^{\circ}\text{C} \dots 3000.00^{\circ}\text{C}$

Pressure of mixture: $p = 0.01\text{bar} \dots 165\text{bar}$

Dry gas mixture ($\psi_w < 1 \cdot 10^{-8}$)

Temperature: $T = -70^{\circ}\text{C} \dots 3000.00^{\circ}\text{C}$

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

Mixture Components

Nr.	Symbol	Name of mixture component
1	Ar	Argon
2	Ne	Neon
3	N ₂	Nitrogen
4	O ₂	Oxygen
5	CO	Carbon Monoxide
6	CO ₂	Carbon Dioxide
7	H ₂ O	Water
8	SO ₂	Sulfur dioxide

Values of the Region Functions

Region	Meaning
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 K exactly
6	Pure water

Reference States of LibHuFlueGas

Fluid	T_0 [K]	p_0 [MPa]	h_0 [kJ/kg]	s_0 [kJ/(kg K)]	u_0 [kJ/kg]
Argon	273.15	0.101325	0	0	-56.79766
Neon	273.15	0.101325	0	0	-112.5436
Nitrogen	273.15	0.101325	0	0	-81.03459
Oxygen	273.15	0.101325	0	0	-70.90573
Carbon monoxide	273.15	0.101325	0	0	-81.08139
Carbon dioxide	273.15	0.101325	0	0	-51.25686
Water	273.16	$611.657 \cdot 10^{-3}$	$0.611872 \cdot 10^{-3}$	0	0
Sulfur dioxide	273.15	0.101325	0	0	-35.45001

Conversion to the Reference States of the publications

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

Fluid	T_0 [K]	p_0 [MPa]	Δh [kJ/kg]	Δs [kJ/(kg K)]	Δu [kJ/kg]	Reference
Argon	298.15	0.101325	-13.23564	$-4.6203961 \cdot 10^{-2}$	-13.23564	[27]
Neon	273.15	0.101325	0	0	0	-
Nitrogen	298.15	0.101325	283.2331	6.744095	283.2331	[28]
Oxygen	298.15	0.100000	-23.20175	$-8.448914 \cdot 10^{-2}$	-23.20175	[29]
Carbon monoxide	273.15	0.101325	0	0	0	-
Carbon dioxide	298.15	0.101325	-21.90979	$-7.564382 \cdot 10^{-2}$	-21.90979	[30]
Water	273.16	$611.657 \cdot 10^{-3}$	0	0	0	[31]
Sulfur dioxide	273.15	0.101325	0	0	0	-

General hint!

If the input values are located outside the range of validity, the result for the calculated function will always be wrong. Please find more exact details on every function and its corresponding range of validity in the enclosed program documentation in chapter 3.

2 Application of FluidLAB in MATLAB

The Add-In FluidLAB has been prepared for the convenient calculation of thermodynamic properties for humid gas mixtures in MATLAB®. FluidLAB allows the user to call functions from the property library LibHuFlueGas for Humid Combustion Gas Mixtures calculated as Ideal Mixture of Real Fluids.

2.1 Installing FluidLAB

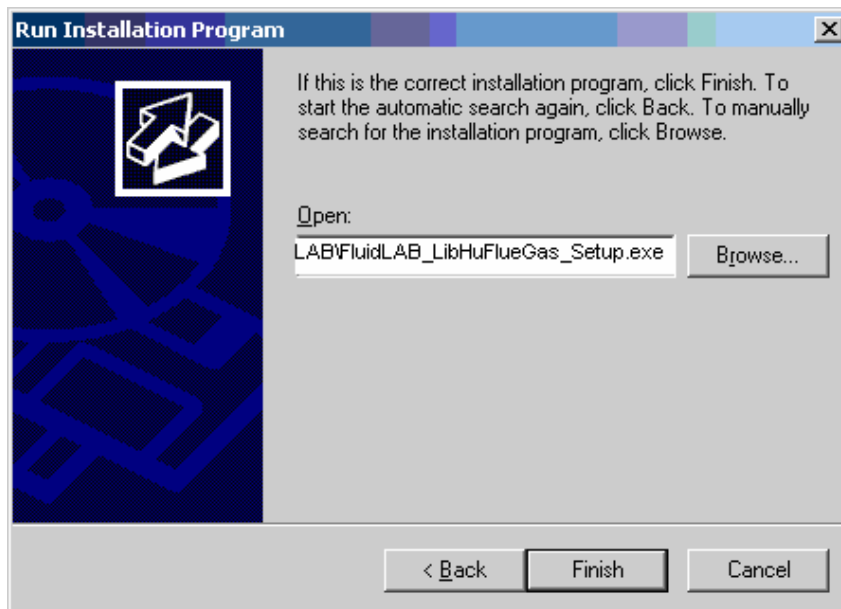
FluidLAB will be installed by means of a self-extracting setup file. In order to start installation click "Start" in the lower task bar of Windows®, then click "Settings" and within the menu "Settings" click "Control Panel". Double-click "Add or Remove Programs" in the window which pops up.

After a short waiting time click "Add New Programs" on the left-hand side of the pop-up window. Click the button "Floppy Disk or CD-ROM" in the dialog box and then click "Next". If the CD-ROM is inserted, click "Open" and the following path will appear:

D:\ FluidLAB_LibHuFlueGas_Setup.exe,

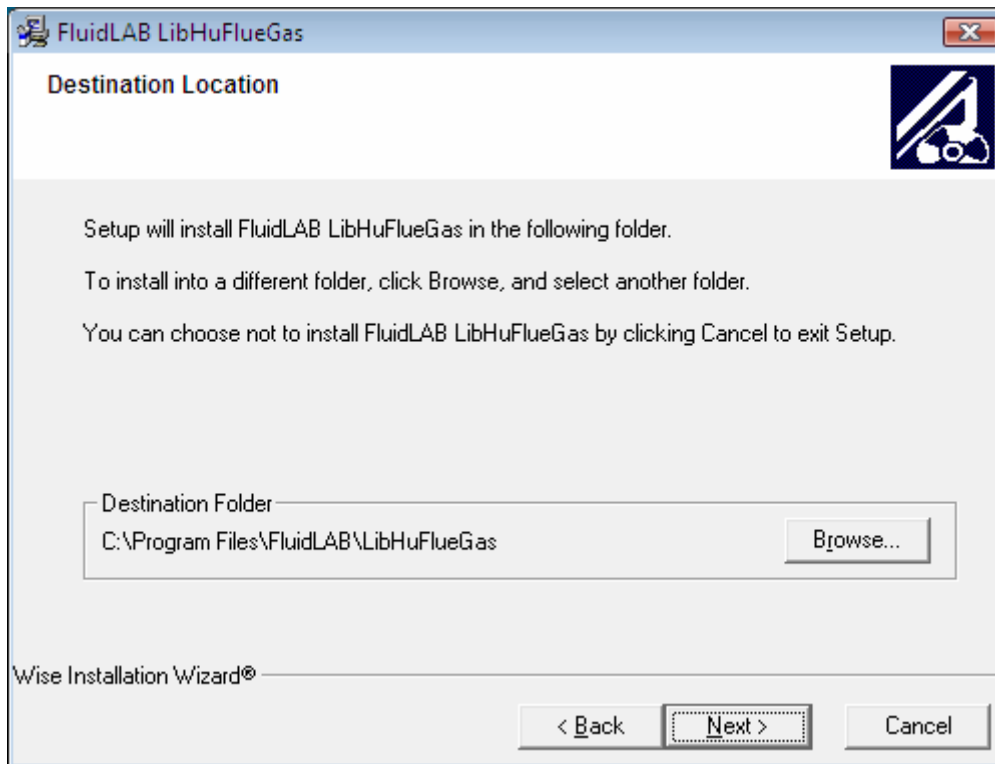
whereas "D" is the drive letter of the CD-ROM drive.

If the file is located on your hard disk drive, then the window which pops-up after you have clicked "Open:" is empty. In this case you have to click "Browse" and search the directory in which the file "FluidLAB_LibHuFlueGas_Setup.exe" is located. Then click the Setup file. After you clicked "Open" the following window pops up:



Installation begins by clicking the "Finish" button. By clicking the "Next>" button, installation continues.

The pop-up window "Destination Location" offers "C:\Program Files\FluidLAB\LibHuFlueGas" to be the default installation directory. (see the following image).



If you wish to change directory, click the "Browse..." button and select your desired directory. The instructions in this documentation refer to the stated default directory. Leave this window by clicking the "Next>" button.

The dialogue window "Start Installation" pops up. Click the "Next>" button to continue installation. The FluidLAB files are now being copied onto your hard disk drive into the created directory. Click the "Finish>" button in the following window to finish installation. Close the "Add or Remove Programs" window and afterwards the "Control Panel" menu.

The installation program has copied the following files into the directory
 "C:\Program Files\FluidLAB\LibHuFlueGas":

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

- MATLAB®-Interface-Programme for calculable functions

a_pTcomp_HuFlueGas.mexw32	R_comp_HuFlueGas.mexw32
cp_hscomp_HuFlueGas.mexw32	Region_hscomp_HuFlueGas.mexw32
cp_phcomp_HuFlueGas.mexw32	Region_phcomp_HuFlueGas.mexw32
cp_pscomp_HuFlueGas.mexw32	Region_pscomp_HuFlueGas.mexw32
cp_pTcomp_HuFlueGas.mexw32	Region_pTcomp_HuFlueGas.mexw32
cp_Tscomp_HuFlueGas.mexw32	Region_Tscomp_HuFlueGas.mexw32
cv_pTcomp_HuFlueGas.mexw32	Rho_pTcomp_HuFlueGas.mexw32
eta_pTcomp_HuFlueGas.mexw32	s_phcomp_HuFlueGas.mexw32
h_pscomp_HuFlueGas.mexw32	s_pTcomp_HuFlueGas.mexw32
h_pTcomp_HuFlueGas.mexw32	sigmaw_T_HuFlueGas.mexw32
h_Tscomp_HuFlueGas.mexw32	T_hscomp_HuFlueGas.mexw32
kappa_pscomp_HuFlueGas.mexw32	T_phcomp_HuFlueGas.mexw32
kappa_pTcomp_HuFlueGas.mexw32	T_pscomp_HuFlueGas.mexw32
lambda_pTcomp_HuFlueGas.mexw32	Tw dew_pcomp_HuFlueGas.mexw32
M_comp_HuFlueGas.mexw32	u_pTcomp_HuFlueGas.mexw32
nue_pTcomp_HuFlueGas.mexw32	v_hscomp_HuFlueGas.mexw32
p_hscomp_HuFlueGas.mexw32	v_phcomp_HuFlueGas.mexw32
p_Tscomp_HuFlueGas.mexw32	v_pscomp_HuFlueGas.mexw32
pdsat_pT_HuFlueGas.mexw32	v_pTcomp_HuFlueGas.mexw32
phi_pTcomp_HuFlueGas.mexw32	v_Tscomp_HuFlueGas.mexw32
Pr_pTcomp_HuFlueGas.mexw32	w_pTcomp_HuFlueGas.mexw32
psiwl_pTcomp_HuFlueGas.mexw32	xw_comp_HuFlueGas.mexw32
psiwsat_pTcomp_HuFlueGas.mexw32	

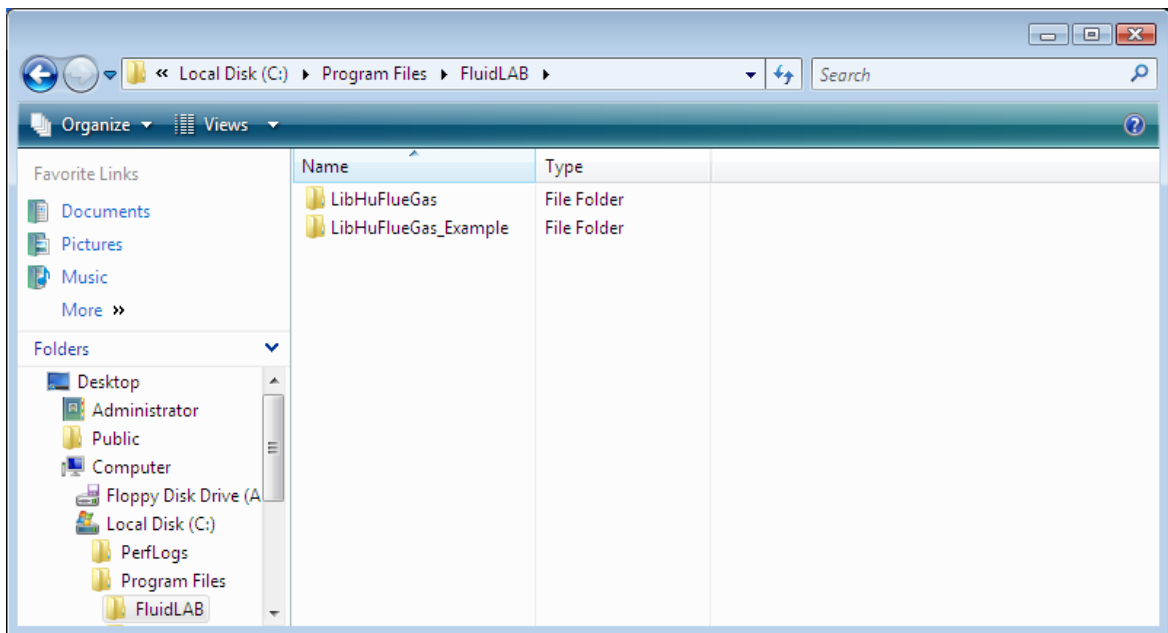
2.2 Example: Calculation of the enthalpy

$h = f(p, t, \psi_1 \dots \psi_8)$ of mixture of gas

The enthalpy h should be calculated from the given mixture pressure p , temperature t and a given composition vector $\psi_1 \dots \psi_8$ for ideal gas.

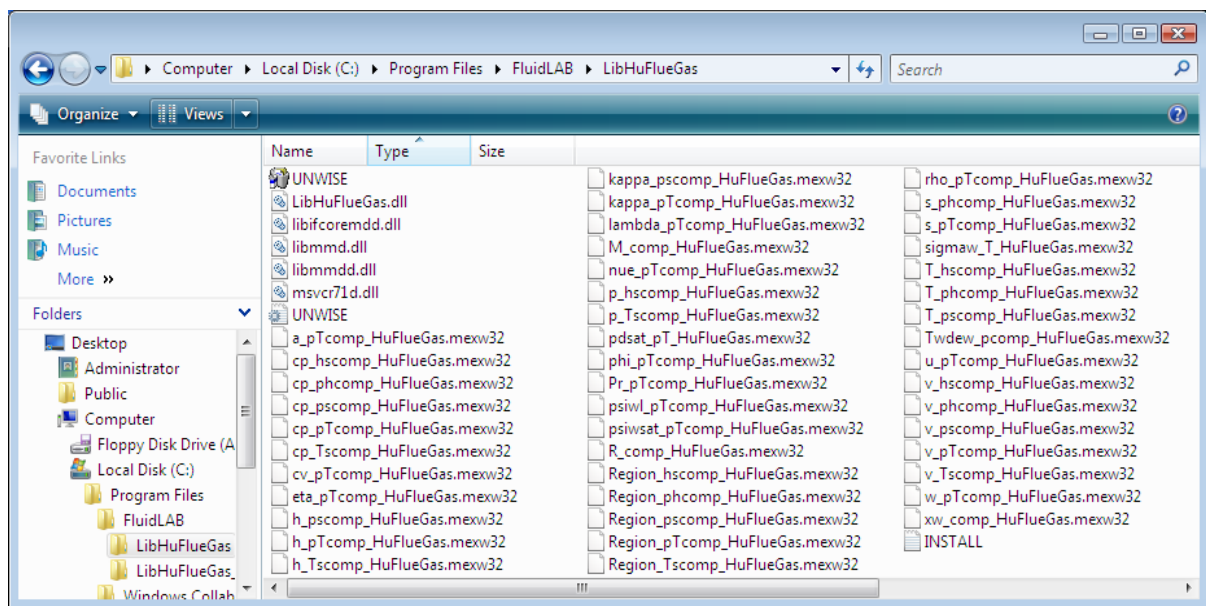
Please carry out the following instructions:

- Start Windows-Explorer®, Total Commander®, My Computer or another file manager program.
The following description refers to Windows-Explorer
- Your Windows-Explorer should be set to Details for a better view. Click the "Views" button and select "Details".
- Switch into the program directory of FluidLAB in which you will find the folder "\LibHuFlueGas"; in the standard case: "C:\Program Files\FluidLAB"
- Create the folder "\LibHuFlueGas_Example". Click "File", then click "New" in the pop-up menu and afterwards select "Folder". Name the new folder "\LibHuFlueGas_Example".
- You will see the following window:



- Switch into the directory "\LibHuFlueGas" within "\FluidLAB", in the standard case: "C:\Program Files\FluidLAB\LibHuFlueGas".

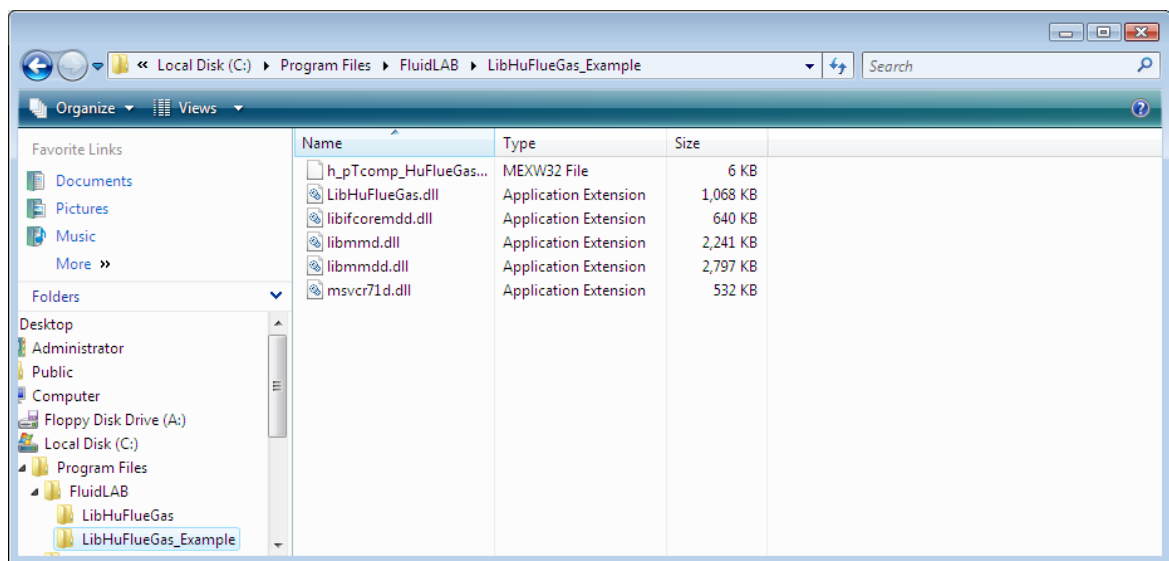
- You will see the following window:



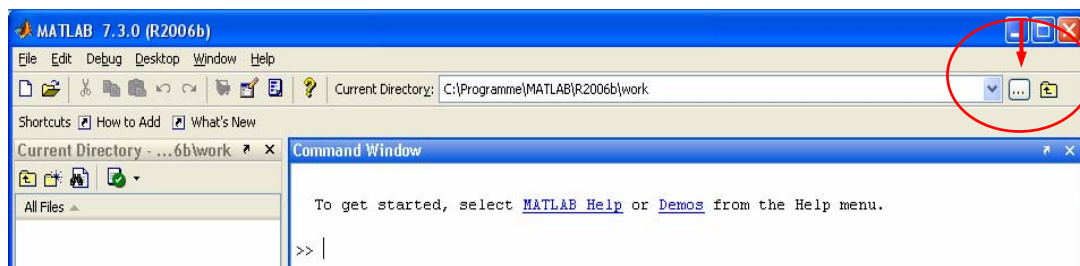
You will now have to copy the following necessary files into the directory "C:\Program Files\FluidLAB\LibHuFlueGas_Example" in order to calculate the function $h = f(p, t, \psi_1 \dots \psi_8)$.

- The following files are necessary:
 - "h_pTcomp_HuFlueGas.mexw32"
 - "LibHuFlueGas.dll"
 - "libifcoremdd.dll"
 - "libmmd.dll"
 - "libmmdd.dll"
 - "msvcr71d.dll"
- Click the file "h_pTcomp_HuFlueGas.mexw32", then click "Edit" in the upper menu bar and select "Copy".
- Switch into the directory "C:\Program Files\FluidLAB\LibHuFlueGas_Example", click "Edit" and select "Paste".
- Repeat these steps in order to copy the other files listed above.

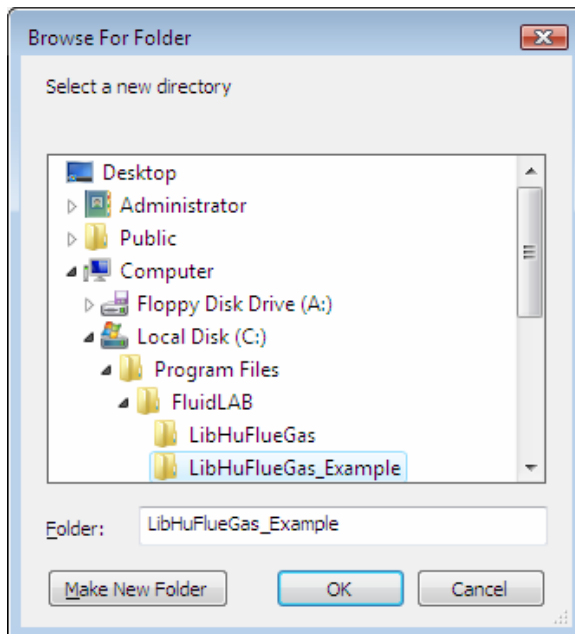
- You will see the following window:



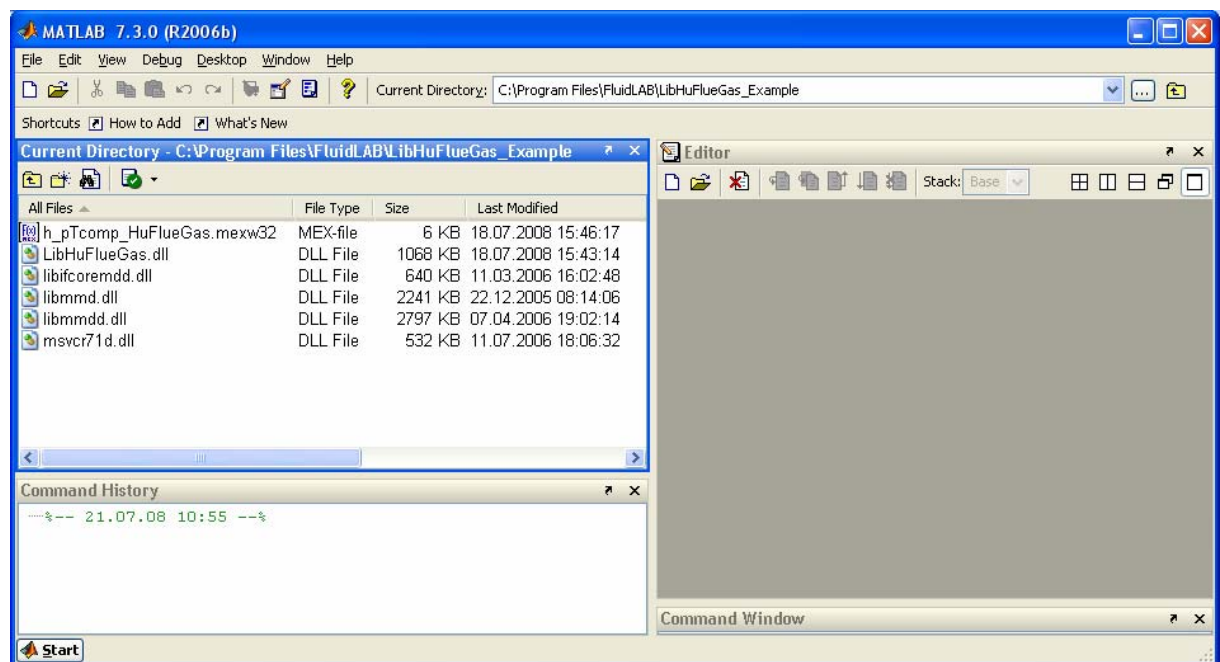
- Start MATLAB (in case you did not start it before).
- Click the button marked in the following image in order to open the folder "LibHuFlueGas_Example" in the window "Current Directory".



- Search and click the directory "C:\Program Files\FluidLAB\LibHuFlueGas_Example" in the pop-up menu (see the following image).



- Confirm your selection by clicking the "OK" button.
- You will see the following window:



According to the table of property functions in chapter 1 you have to call the function "h_pTcomp_HuFlueGas" as follows for calculating $h = f(p, t, (1 \dots (8))$

Enter the composition vector as follows:

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

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

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

ψ_1	for Argon	Ar	$\Rightarrow$ The value 0.0088
ψ_2	for Neon	Ne	$\Rightarrow$ The value 0
ψ_3	for Nitrogen	N2	$\Rightarrow$ The value 0.7480
ψ_4	for Oxygen	O2	$\Rightarrow$ The value 0.1352
ψ_5	for Carbon monoxide	CO	$\Rightarrow$ The value 0
ψ_6	for Carbon dioxide	CO2	$\Rightarrow$ The value 0.0330
ψ_7	for Water	H2O	$\Rightarrow$ The value 0.0750
ψ_8	for Sulphur dioxide	SO2	$\Rightarrow$ The value 0

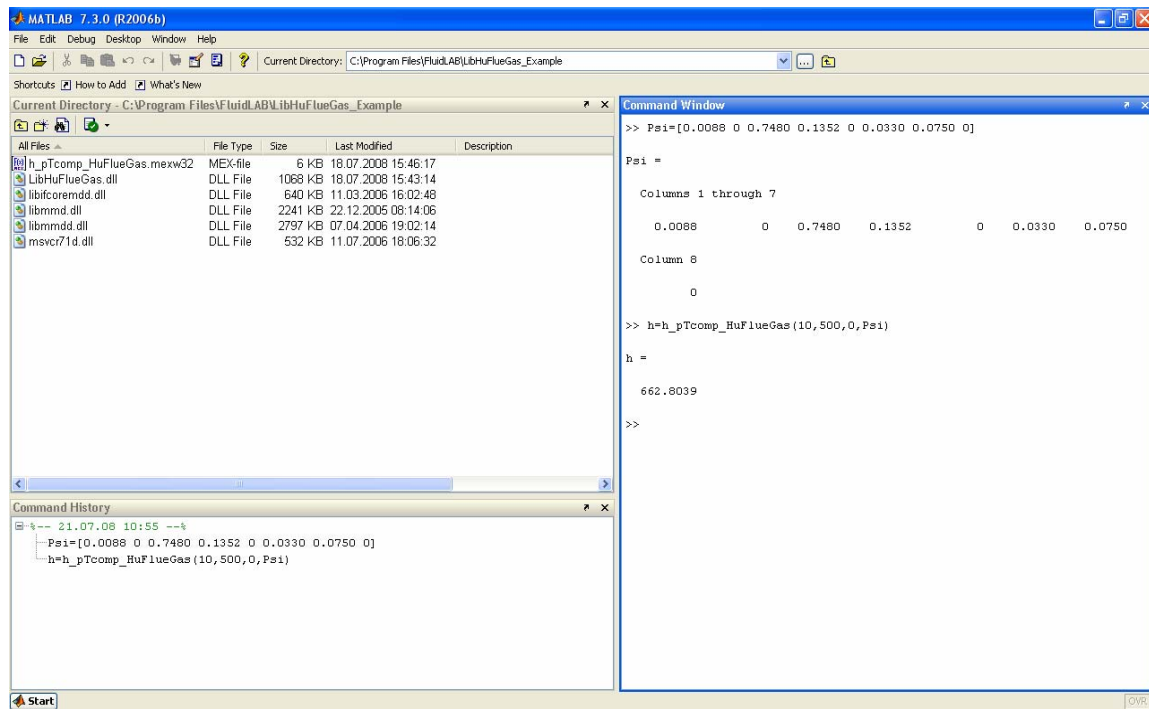
- Type "h=h_pTcomp_HuFlueGas(10,500,0,Psi)" within the "Command Window".

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

- First operand: Value for $p = 10$ bar
(Range of validity: $p = 0.01$ bar ... 1000 bar)
- Second operand: Value for $t = 500$ °C
(Range of validity: $t = -70$ °C ... 3000.00°C)
- Third operand: Value for $art = 0$
(Chose between: $art = 1$ for input in mass fractions $\xi_1 \dots \xi_8$
 $art = 0$ for input in mole fractions, i.e. volume fractions $\psi_1 \dots \psi_8$)
- Fourth operand: Vector for the composition Psi (see above).

- Confirm your entry by pressing the "ENTER" button.

- You will see the following window:



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

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

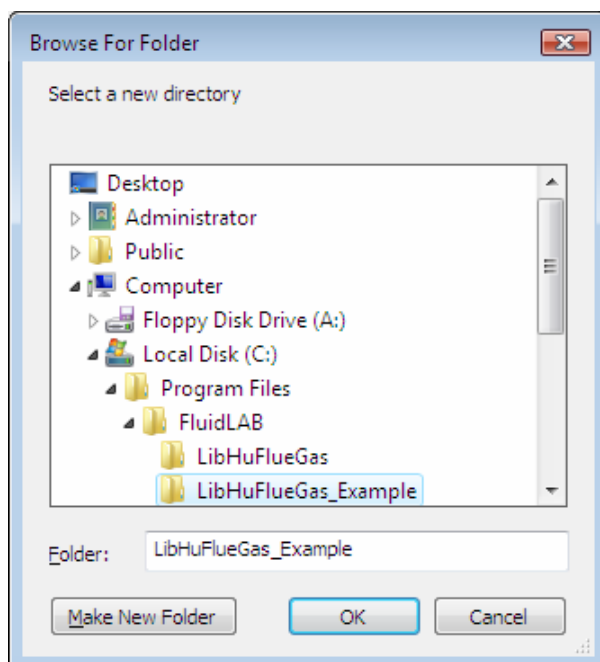
2.3 Example: Calculation of the enthalpy

$h = f(p, t, \psi_1 \dots \psi_8)$ of mixture of gas in a M-File

- Please follow the instructions from page 2/4 to 2/6.
- Start MATLAB (in case you did not start it before).
- Click the button marked in the following image in order to open the folder "LibHuFlueGas_Example" in the window "Current Directory".



- Search and click the directory "C:\Program Files\FluidLAB\LibHuFlueGas_Example" in the pop-up menu (see the following image).

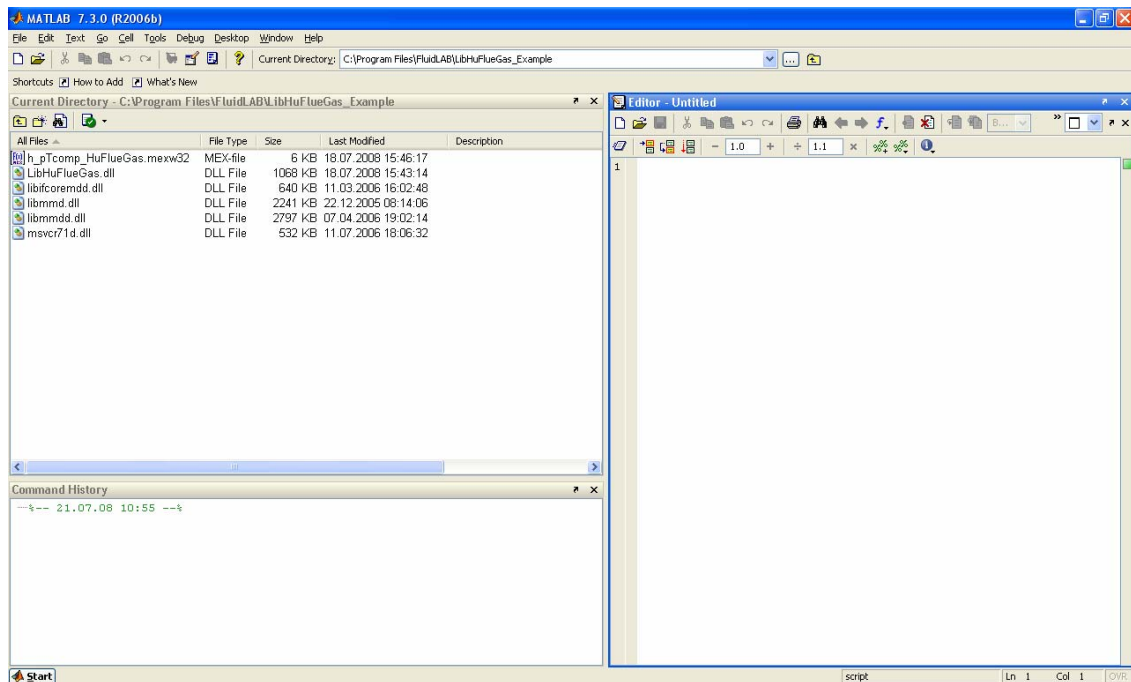


- Confirm your selection by clicking the "OK" button.

- First of all you need to create a M-File in MATLAB. Within MATLAB click "File", then select "New" and afterwards click "M-File".
- In case the "Editor" window appears as a separate window, you can embed it into MATLAB by clicking the arrow (see the following image) in order to obtain a better view.



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



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

Text to be written:	Explanation:
<code>% h_pTcomp_HuFlueGas.m</code>	file name as comment
<code>%%</code>	paragraph separation
<code>p=10; % pressure in bar</code>	declaration of the variables pressure, temperature, art and composition of mixture
<code>t=500; % temperature in °C</code>	
<code>art=0; % input values in mole fractions</code>	
<code>Psi=[0.0088 0 0.7480 0.1352 0 0.0330 0.0750 0]</code>	
<code>% composition</code>	paragraph separation
<code>%%</code>	
<code>h=h_pTcomp_HuFlueGas(p, t, art, Psi)</code>	function call
<code>%%</code>	paragraph separation

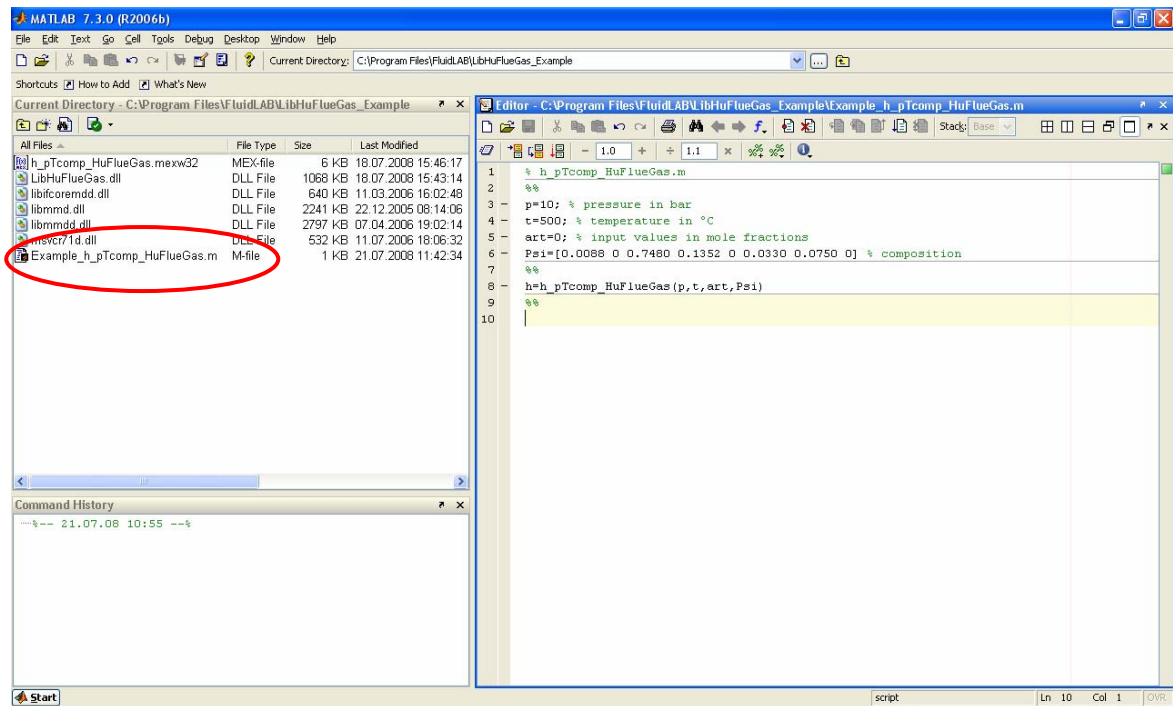
- Remarks:

- The program interprets the first line which starts with "%" to be a data description in "Current Directory"
- Paragraph separations which are mandatory are being realised through "%%". By this, declaration of variables and calculation instructions are also being separated.
- The words which are printed in green, start with "%" and stand behind the variables are comments. In fact they are not necessary but they are reasonable for your overview and comprehensibility.
- You have to leave out the semicolons behind the numerical values if you wish to see the result for h and the input parameters as well.

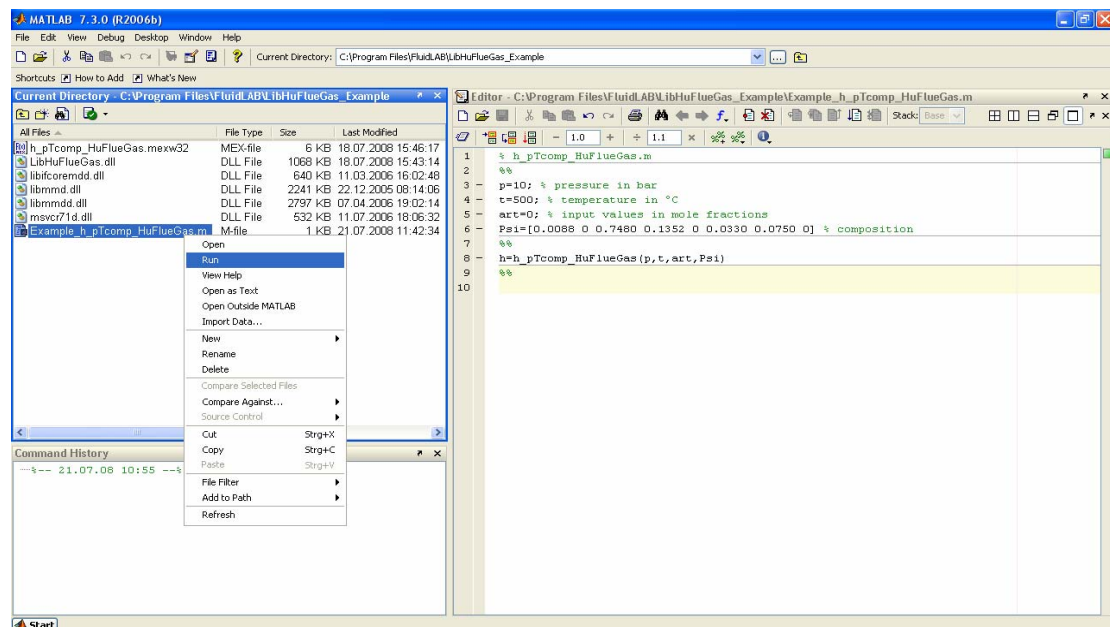
The values of the function parameters in their corresponding units stand for:

- First operand: Value for $p = 10$ bar
(Range of validity: $p = 0.01$ bar ... 1000 bar)
- Second operand: Value for $t = 500$ °C
(Range of validity: $t = - 70$ °C ... 3000.00 °C)
- Third operand: Value for $art = 0$
(Chose between: $art = 1$ for input in mass fractions $\xi_1 \dots \xi_8$
 $art = 0$ for input in mole fractions, i.e. volume fractions $\psi_1 \dots \psi_8$)
- Fourth operand: Vector for the composition Psi (see above).
- Save the "M-File" by clicking the "File" button and then click "Save As...".
- The menu "Save file as:" pops up; therein the folder name "LibHuFlueGas_Example" must be displayed next to "Save in:"
- Next to "File name" you have to type in "Example_h_pTcomp_HuFlueGas.m" and afterwards click the "Save" button.

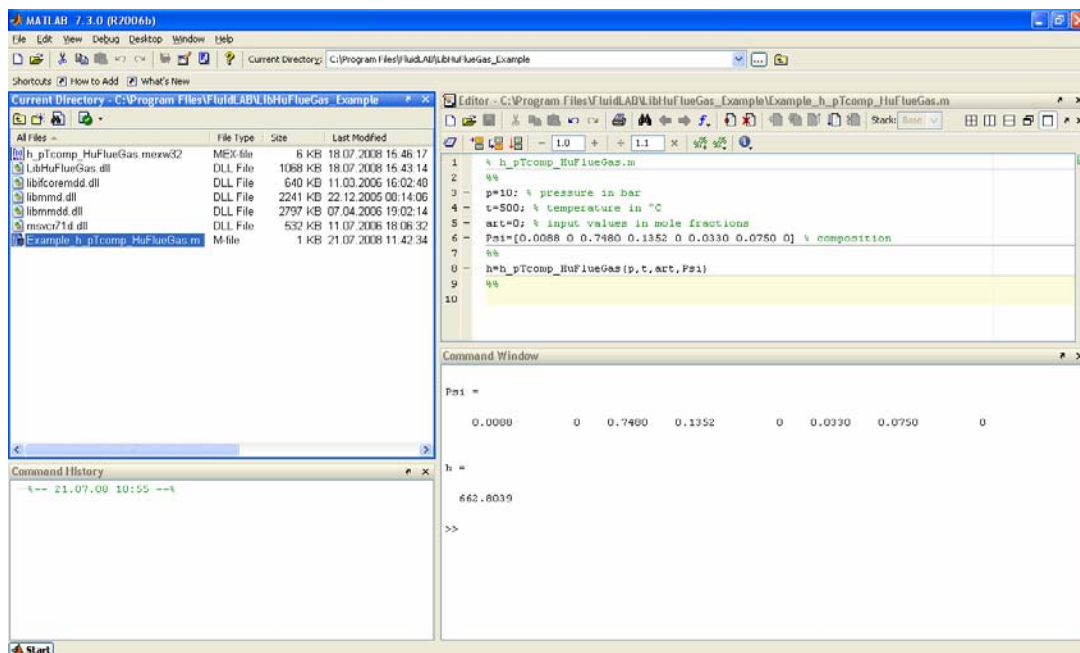
- You will see the following window:



- Within the window "Current Directory" the file "Example_h_pTcomp_HuFlueGas.m" appears.
- Right-click this file and click "Run" in the menu which pops up (see the following image).



- You will see the following window:



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

To be able to calculate other values, you have to copy the associated mexw32 files as well because MATLAB can only call functions if they are located in the window "Current Directory". The example calculated can be found in the directory "C:\Programme\FluidLAB\LibHuFlueGas_Example" and you may use it as a basis for further calculations with FluidLAB.

2.4 Uninstalling LibHuFlueGas in FluidLAB

In order to remove the property library LibHuFlueGas from your hard disk drive in Windows®, click "Start" in the lower task bar, then "Settings" and "Control Panel". Afterwards double-click "Add or Remove Programs". Click "FluidLAB LibHuFlueGas" in the list box (after it has finished loading) of the menu "Add or Remove Programs" which pops up and afterwards click the "Change/Remove" button. Mark "Automatic" in the next dialogue window and click the "Next>" button. Confirm the following menu "Perform Uninstall" by clicking the "Finish" button. Now close the windows "Add or Remove Programs" and "Control Panel". FluidLAB has been removed.

If there is installed no other library than LibHuFlueGas then the directory "FluidLAB" will be removed as well.

3 Program documentation

Thermal Diffusivity $a = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:

a_pTcomp_HuFlueGas

Fortran Programs:

```
REAL*8 FUNCTION A_PT_HUFLUEGAS (REAL*8 P, REAL*8 T, INTEGER*4 ART,
                                REAL*8 COMP)
```

Input values:

p - Pressure p in bar

t - Temperature t in °C

art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ

comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

a_pTcomp_HuFlueGas, a - temperature conductivity in m²/s

Range of validity:

Pressure p : from 0.01 bar to 1000 bar

Temperature t : from - 70 °C to 3000.00°C

Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol

Partial pressures of CO₂ and SO₂ less than saturation pressures.

Comments:

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

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

Results for wrong input values:

a_pTcomp_HuFlueGas, a = -1

References:

Gas	ρ , c_p - ideal part	ρ , c_p - real part	λ
Ar	[26]	[27]	[33]
Ne	[26]	-	[34],[35],[40],[41]
N ₂	[26]	[28]	[42]
O ₂	[26]	[29]	[37]
CO	[26]	-	[38]
CO ₂	[26]	[30]	[43]
H ₂ O	[26]	[31]	[16]
SO ₂	[26]	-	[34],[35],[40]

Specific Isobaric Heat Capacity $c_p = f(h, s, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

cp_hscomp_HuFlueGas

Fortran Programs:

```
REAL*8 FUNCTION CP_HS_HUFLUEGAS (REAL*8 H, REAL*8 S, INTEGER*4 ART,
                                REAL*8 COMP)
```

Input values:

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

Result:

cp_hscomp_HuFlueGas, cp - Specific isobaric heat capacity in kJ/(kg K)

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Calculation:

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

Results for wrong input values:

cp_hscomp_HuFlueGas, cp = -1.10¹⁰⁰

References:

Gas	c_p, h, s - ideal part	c_p, h, s - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

Specific Isobaric Heat Capacity $c_p = f(p, h, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

cp_phcomp_HuFlueGas

Fortran Programs:

REAL*8 FUNCTION CP_PH_HUFLUEGAS (REAL*8 P, REAL*8 S, INTEGER*4 ART,
REAL*8 COMP)

Input values:

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

Result:

cp_phcomp_HuFlueGas, c_p - specific isobaric heat capacity in kJ/(kg K)

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

cp_phcomp_HuFlueGas, $c_p = -1 \cdot 10^{100}$

Reference:

Gas	$c_{p,h}$ - ideal part	$c_{p,h}$ - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

Specific Isobaric Heat Capacity $c_p = f(p, s, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

cp_pscomp_HuFlueGas

Fortran Programs:

REAL*8 FUNCTION CP_PS_HUFLUEGAS (REAL*8 P, REAL*8 S, INTEGER*4 ART,
REAL*8 COMP)

Input values:

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

Result:

cp_pscomp_HuFlueGas, c_p - specific isobaric heat capacity in kJ/(kg K)

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

cp_pscomp_HuFlueGas, $c_p = -1 \cdot 10^{100}$

Reference:

Gas	$c_{p,s}$ - ideal part	$c_{p,s}$ - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

Specific Isobaric Heat Capacity $c_p = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMat and FluidLAB:

cp_pTcomp_HuFlueGas

Fortran Programs:

REAL*8 FUNCTION CP_PT_HUFLUEGAS (REAL*8 P, REAL*8 T, INTEGER*4 ART,
REAL*8 COMP)

Input values:

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

Result:

cp_pTcomp_HuFlueGas, c_p - specific isobaric heat capacity in kJ/(kg K)

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values:

cp_pTcomp_HuFlueGas, $c_p = -1 \cdot 10^{100}$

Reference:

Gas	c_p - ideal part	c_p - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

Specific Isobaric Heat Capacity $c_p = f(t, s, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

cp_Tscomp_HuFlueGas

Fortran Programs:

```
REAL*8 FUNCTION CP_TS_HUFLUEGAS (REAL*8 T , REAL*8 S, INTEGER*4 ART,
                                REAL*8 COMP)
```

Input values:

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

Result:

cp_Tscomp_HuFlueGas, c_p - specific isobaric heat capacity in kJ/(kg K)

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

cp_Tscomp_HuFlueGas, $c_p = -1 \cdot 10^{100}$

Reference:

Gas	$c_{p,s}$ - ideal part	$c_{p,s}$ - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

Specific Isochoric Heat Capacity $c_v = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

cv_pTcomp_HuFlueGas

Fortran Programs:

REAL*8 FUNCTION CV_PT_HUFLUEGAS (REAL*8 P, REAL*8 T, INTEGER*4 ART,
REAL*8 COMP)

Input values:

p - Pressure p in bar
t - Temperature t in °C
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

cv_pTcomp_HuFlueGas, cv - specific isochoric heat capacity in kJ/(kg K)

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

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

Results for wrong input values:

cv_pT_HuFlueGas, cv = $-1 \cdot 10^{100}$

References:

Gas	cv - ideal part	cv - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

Dynamic Viscosity $\eta = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

eta_pTcomp_HuFlueGas

Fortran Programs:

```
REAL*8 FUNCTION ETA_PT_HUFLUEGAS (REAL*8 P, REAL*8 T, INTEGER*4 ART,
                                   REAL*8 COMP)
```

Input Values:

p - Pressure p in bar
t - Temperature t in °C
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass or mole fractions of mixture of gases

Result:

eta_pTcomp_HuFlueGas, eta - dynamic viscosity in Pa s

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

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

Results for wrong input values:

eta_pTcomp_HuFlueGas, Eta = $-1 \cdot 10^{100}$

References:

Gas	η
Ar	[33]
Ne	[34]
N ₂	[36]
O ₂	[37]
CO	[38]
CO ₂	[39]
H ₂ O	[17]
SO ₂	[34]

Specific Enthalpy $h = f(p, s, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:

Fortran Programs:

```
REAL*8 FUNCTION H_PS_HUFLUEGAS (REAL*8 P, REAL*8 S, INTEGER*4 ART,
                                REAL*8 COMP)
```

Input Values:

p - Pressure p in bar
s - Entropy s in kJ/(kg K)
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

h - specific enthalpy in kJ/kg

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
 Pressure p : from 0.01 bar to 1000 bar
 Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Calculation:

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

Results for wrong input values:

h = -1 \cdot 10^{100}

References:

Gas	h, s - ideal part	h, s - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N ₂	[26]	[28]	-
O ₂	[26]	[29]	-
CO	[26]	-	-
CO ₂	[26]	[30]	-
H ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Zittau/Goerlitz University of Applied Sciences, Department of Technical Thermodynamics, Professor H.-J. Kretschmar, Dr. I. Stöcker

Specific Enthalpy $h = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

h_pTcomp_HuFlueGas

Fortran Programs:

REAL*8 FUNCTION H_PT_HUFLUEGAS (REAL*8 P, REAL*8 T, INTEGER*4 ART,
REAL*8 COMP)

Input values:

p - Pressure p in bar
t - Temperature t in °C
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

h_pTcomp_HuFlueGas - specific enthalpy in kJ/kg

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Result for incorrect input values:

h_pTcomp_HuFlueGas = -1.10¹⁰⁰

Reference:

Gas	h - ideal part	h - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N ₂	[26]	[28]	-
O ₂	[26]	[29]	-
CO	[26]	-	-
CO ₂	[26]	[30]	-
H ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Specific Enthalpy $h = f(t, s, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:
Tscomp_HuFlueGas
Fortran Programs:

```
REAL*8 FUNCTION H_TS_HUFLUEGAS (REAL*8 T , REAL*8 S, INTEGER*4 ART,
                                REAL*8 COMP)
```

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
 comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:
Tscomp_HuFlueGas - specific enthalpy in kJ/kg
Range of validity:

Temperature t : from - 70 °C to 3000.00°C
 Pressure p : from 0.01 bar to 1000 bar
 Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Result for incorrect input values:
Tscomp_HuFlueGas = -1.10¹⁰⁰
Reference:

Gas	h, s ideal part	h, s real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N ₂	[26]	[28]	-
O ₂	[26]	[29]	-
CO	[26]	-	-
CO ₂	[26]	[30]	-
H ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Isentropic exponent $\kappa = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:

kappa_pTcomp_HuFlueGas

Fortran Programs:

```

      REAL*8 FUNCTION KAPPA_PT_HUFLUEGAS (REAL*8 P, REAL*8 T, INTEGER*4
ART,
                                                    REAL*8 COMP)

```

Input Values:

p - Pressure p in bar
 t - Temperature t in °C
 art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ

 comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

kappa_pTcomp_HuFlueGas, kappa – Isentropic exponent in -

Range of validity:

Pressure p : from 0.01 bar to 1000 bar
 Temperature t : from - 70 °C to 3000.00°C
 Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$): $\kappa = -\frac{v}{p} \cdot \left(\frac{\partial p}{\partial v} \right)_T \cdot \frac{c_p}{c_v}$
- for liquid fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water
- for ice fog ($\psi_w > \psi_{w,sat}$, $t < 0.01$ °C) as saturated humid gas mixture

Results for wrong input values:

 kappa_pTcomp_HuFlueGas, kappa = -1·10¹⁰⁰
References:

Gas	v, c_p, c_v - ideal part	v, c_p, c_v - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

Isentropic exponent $\kappa = f(p, s, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:

kappa_pscomp_HuFlueGas

Fortran Programs:

```

      REAL*8 FUNCTION KAPPA_PS_HUFLUEGAS (REAL*8 P, REAL*8 S, INTEGER*4
      ART,
                                                    REAL*8 COMP)

```

Input Values:

p - Pressure p in bar
 s - Entropy s in kJ/(kg K)
 art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ

 comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

kappa_pscomp_HuFlueGas, kappa – Isentropic exponent in -

Range of validity:

Pressure p : from 0.01 bar to 1000 bar
 Temperature t : from - 70 °C to 3000.00°C
 Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$): $\kappa = -\frac{v}{p} \cdot \left(\frac{\partial p}{\partial v} \right)_T \cdot \frac{c_p}{c_v}$
- for liquid fog ($\psi_w > \psi_{w,sat}$) as ideal mixture of saturated humid gas and liquid water
- for ice fog ($\psi_w > \psi_{w,sat}$, $t < 0.01$ °C) as saturated humid gas mixture

Results for wrong input values:

 kappa_pscomp_HuFlueGas, kappa = -1·10¹⁰⁰
References:

Gas	v, c_p, c_v - ideal part	v, c_p, c_v - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

Thermal Conductivity $\lambda = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

lambda_pTcomp_HuFlueGas

Fortran Programs:

```
REAL*8 FUNCTION LAMBDA_PT_HUFLUEGAS (REAL*8 P, REAL*8 T, INTEGER*4
ART,
REAL*8 COMP)
```

Input Values:

p - Pressure p in bar
t - Temperature t in °C
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass or mole fractions of mixture of gases

Result:

lambda_pTcomp_HuFlueGas, lambda - Thermal conductivity in W/(m K)

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ 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

Results for wrong input values:

lambda_pTcomp_HuFlueGas, lambda = $-1 \cdot 10^{100}$

References:

Gas	λ
Ar	[33]
Ne	[34],[35],[40],[41]
N ₂	[42]
O ₂	[37]
CO	[38]
CO ₂	[43]
H ₂ O	[16]
SO ₂	[34],[35],[40]

Molar Mass $M = f(\xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

M_comp_HuFlueGas

Fortran Programs:

REAL*8 FUNCTION M_HUFLUEGAS (INTEGER*4 ART, REAL*8 COMP)

Input Values:

art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ

comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass or mole fractions of mixture of gases

Result:

M_comp_HuFlueGas, M - Molar mass in kg/kmol

Results for wrong input values:

M_comp_HuFlueGas, M = -1

Kinematic Viscosity $\nu = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:

nue_pTcomp_HuFlueGas

Fortran Programs:

```
REAL*8 FUNCTION NUE_PT_HUFLUEGAS (REAL*8 P, REAL*8 T, INTEGER*4 ART,
                                   REAL*8 COMP)
```

Input Values:

p - Pressure p in bar

t - Temperature t in °C

art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ

comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

nue_pTcomp_HuFlueGas, nue - Kinematic Viscosity in m^2/s
Range of validity:

Pressure p : from 0.00001 bar to 50 bar

Temperature t : from - 70 °C to 3000.00°C

Mole fraction of water ψ_w : $0 \leq \psi_w \leq 0.99$ kmol/kmol

Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Results for wrong input values:

nue_pTcomp_HuFlueGas, nue = $-1 \cdot 10^{100}$
References:

Gas	ν - ideal part	ν - real part	λ
Ar	[26]	[27]	[33]
Ne	[26]	-	[34],[35],[40],[41]
N ₂	[26]	[28]	[42]
O ₂	[26]	[29]	[37]
CO	[26]	-	[38]
CO ₂	[26]	[30]	[43]
H ₂ O	[26]	[31]	[16]
SO ₂	[26]	-	[34],[35],[40]

Pressure $p = f(h, s, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:

p_hscomp_HuFlueGas

Fortran Programs:

```
REAL*8 FUNCTION P_HS_HUFLUEGAS (REAL*8 H, REAL*8 S, INTEGER*4 ART,
                                REAL*8 COMP)
```

Input values:

h - Enthalpy h in kJ/kg
s - Entropy s in kJ/(kg K)
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ

comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

p_hscomp_HuFlueGas, p - Pressure in bar

Range of validity:

Pressure p : from 0.01 bar to 50 bar
Temperature t : from - 70 °C to 3000.00°C
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Iteration of t and p from $h(p, t, \text{comp})$ and $s(p, t, \text{comp})$ and calculation:
- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w, \text{sat}}$) as ideal mixture of real gases (dry gas and steam)
- for fog ($\psi_w > \psi_{w, \text{sat}}$) as ideal mixture of saturated humid gas and liquid water or water ice, no calculation for liquid-ice fog at 0.01 °C
- consideration of effects of dissociation for temperatures greater than 500 °C

Result for incorrect input values:

p_hscomp_HuFlueGas, p = -1·10¹⁰⁰

Reference:

Gas	h, s - ideal part	h, s - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N ₂	[26]	[28]	-
O ₂	[26]	[29]	-
CO	[26]	-	-
CO ₂	[26]	[30]	-
H ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Pressure $p = f(t, s, \xi_1 \dots \xi_8$ or $\psi_1 \dots \psi_8$)

Name in FluidEXL, FluidMAT and FluidLAB:

p_Tscomp_HuFlueGas

Fortran Programs:

REAL*8 FUNCTION P_TS_HUFLUEGAS (REAL*8 T, REAL*8 S, INTEGER*4 ART,
REAL*8 COMP)

Input values:

t - Temperature t in °C
s - Entropy s in kJ/(kg K)
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

p_Tscomp_HuFlueGas, p - Pressure in bar

Range of validity:

Pressure p : from 0.01 bar to 50 bar
Temperature t : from - 70 °C to 3000.00°C
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Iteration of p from $s(p, t, \text{comp})$ and calculation:
- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w, \text{sat}}$) as ideal mixture of real gases (dry gas and steam)
- for fog ($\psi_w > \psi_{w, \text{sat}}$) as ideal mixture of saturated humid gas and liquid water or water ice, no calculation for liquid-ice fog at 0.01 °C
- consideration of effects of dissociation for temperatures greater than 500 °C

Result for incorrect input values:

p_Tscomp_HuFlueGas, p = -1.10¹⁰⁰

Reference:

Gas	T, s - ideal part	T, s - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N ₂	[26]	[28]	-
O ₂	[26]	[29]	-
CO	[26]	-	-
CO ₂	[26]	[30]	-
H ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Saturation pressure of water $p_{\text{dsat}} = f(p, t)$

Name in FluidEXL, FluidMAT and FluidLAB:

pdsat_pT_HuFlueGas

Fortran Programs:

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

Input values:

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

Result:

pdsat_pT_HuFlueGas, pdsat - Saturation pressure of water in bar

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar

Comments:

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

Result for incorrect input values:

pdsat_pT_HuFlueGas, pdsat = $-1 \cdot 10^{100}$

Reference:

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

Relative Humidity $\varphi = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:

phi_pTcomp_HuFlueGas

Name in Fortran:

REAL*8 FUNCTION PHI_PT_HUFLUEGAS (REAL*8 P, REAL*8 T, INTEGER*4 ART,
REAL*8 COMP)

Input values:

p - Pressure p in bar
t - Temperature t in °C
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

phi_pTcomp_HuFlueGas, phi - Relative humidity in %

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar $\leq p \leq$ 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

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

Result for incorrect input values:

phi_pTcomp_HuFlueGas, phi = $-1 \cdot 10^{100}$

Reference:

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

Prandtl Number $Pr = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:

Pr_pTcomp_HuFlueGas

Name in Fortran:

REAL*8 FUNCTION PR_PT_HUFLUEGAS (REAL*8 P, REAL*8 T, INTEGER*4 ART,
REAL*8 COMP)

Input values:

- p - Pressure p in bar
t - Temperature t in °C
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

Pr_pTcomp_HuFlueGas, Pr – Prandtl Number

Range of validity:

- Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

- Prandtl-number $Pr = \frac{\nu}{a} = \frac{\eta \cdot c_p}{\lambda}$
- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w,sat}$) 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_pTcomp_HuFlueGas, Pr = -1.10¹⁰⁰

Reference:

Gas	c_p - ideal part	c_p - real part	η	λ
Ar	[26]	[27]	[33]	[33]
Ne	[26]	-	[34]	[34],[35],[40],[41]
N ₂	[26]	[28]	[36]	[42]
O ₂	[26]	[29]	[37]	[37]
CO	[26]	-	[38]	[38]
CO ₂	[26]	[30]	[39]	[43]
H ₂ O	[26]	[31]	[17]	[16]
SO ₂	[26]	-	[34]	[34],[35],[40]

Gas constant $R = f(\xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

R_comp_HuFlueGas

Name in Fortran:

REAL*8 FUNCTION R_HUFLUEGAS (INTEGER*4 ART, REAL*8 COMP)

Input values:

art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ

comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

R_comp_HuFlueGas, R - Gas constant in kJ/(kg K)

Result for incorrect input values:

R_comp_HuFlueGas, R = $-1 \cdot 10^{100}$

Reference: [32]

Region = f($h, s, \xi_1 \dots \xi_8$ or $\psi_1 \dots \psi_8$)

Name in FluidEXL, FluidMAT and FluidLAB:

Region_hscomp_HuFlueGas

Name in Fortran:

INTEGER*4 FUNCTION REGION_TS_HUFLUEGAS (REAL*8 T, REAL*8 S,
INTEGER*4 ART, REAL*8 COMP)

Input values:

h - Enthalpy h in kJ/kg
s - Entropy s in kJ/(kg K)
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

Region_hscomp_HuFlueGas - Point of state of humid gas mixture
= 0 → Out of range of validity
= 1 → Dry gas mixture
= 2 → Unsaturated Gas mixture
= 3 → Liquid fog
= 4 → Ice fog
= 5 → Liquid-ice fog at 0.01 °C exactly

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar $\leq p \leq$ 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Result for incorrect input values:

Region_hscomp_HuFlueGas = 0

Reference:

Gas	h, s - ideal part	h, s - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

$Region = f(p, h, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

Region_phcomp_HuFlueGas

Name in Fortran:

INTEGER*4 FUNCTION REGION_PH_HUFLUEGAS (REAL*8 P, REAL*8 H,
INTEGER*4 ART, REAL*8 COMP)

Input values:

p - Pressure p in bar
h - Enthalpy h in kJ/kg
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ

comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

Region_phcomp_HuFlueGas - Point of state of humid gas mixture
 = 0 → Out of range of validity
 = 1 → Dry gas mixture
 = 2 → Unsaturated Gas mixture
 = 3 → Liquid fog
 = 4 → Ice fog
 = 5 → Liquid-ice fog at 0.01 °C exactly

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar

Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Result for incorrect input values:

Region_phcomp_HuFlueGas = 0

Reference:

Gas	h - ideal part	h - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

$Region = f(p, s, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

Region_pscomp_HuFlueGas

Name in Fortran:

INTEGER*4 FUNCTION REGION_PS_HUFLUEGAS (REAL*8 P, REAL*8 S,
INTEGER*4 ART, REAL*8 COMP)

Input values:

p - Pressure p in bar
s - Entropy s in kJ/(kg K)
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ

comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

Region_pscomp_HuFlueGas - Point of state of humid gas mixture
= 0 → Out of range of validity
= 1 → Dry gas mixture
= 2 → Unsaturated Gas mixture
= 3 → Liquid fog
= 4 → Ice fog
= 5 → Liquid-ice fog at 0.01 °C exactly

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Result for incorrect input values:

Region_pscomp_HuFlueGas = 0

Reference:

Gas	h - ideal part	h - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

$Region = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

Region_pTcomp_HuFlueGas

Name in Fortran:

INTEGER*4 FUNCTION REGION_PT_HUFLUEGAS (REAL*8 P, REAL*8 T,
INTEGER*4 ART, REAL*8 COMP)

Input values:

p - Pressure p in bar
t - Temperature t in °C
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ

comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

Region_pTcomp_HuFlueGas - Point of state of humid gas mixture
 = 0 → Out of range of validity
 = 1 → Dry gas mixture
 = 2 → Unsaturated Gas mixture
 = 3 → Liquid fog
 = 4 → Ice fog
 = 5 → Liquid-ice fog at 0.01 °C exactly

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values:

Region_pTcomp_HuFlueGas = 0

$\text{Region} = f(t, s, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
--

Name in FluidEXL, FluidMAT and FluidLAB:

Region_Tscomp_HuFlueGas

Name in Fortran:

INTEGER*4 FUNCTION REGION_TS_HUFLUEGAS (REAL*8 T, REAL*8 S,
INTEGER*4 ART, REAL*8 COMP)

Input values:

t - Temperature t in °C
s - Entropy s in kJ/(kg K)
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

Region_Tscomp_HuFlueGas - Point of state of humid gas mixture
= 0 → Out of range of validity
= 1 → Dry gas mixture
= 2 → Unsaturated Gas mixture
= 3 → Liquid fog
= 4 → Ice fog
= 5 → Liquid-ice fog at 0.01 °C exactly

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Result for incorrect input values:

Region_Tscomp_HuFlueGas = 0

Reference:

Gas	h - ideal part	h - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

Density $\rho = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:

rho_pTcomp_HuFlueGas

Name in Fortran:

```
REAL*8 FUNCTION RHO_PT_HUFLUEGAS (REAL*8 P, REAL*8 T, INTEGER*4 ART,
                                REAL*8 COMP)
```

Input values:

p - Pressure p in bar
t - Temperature t in °C
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ

comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

rho_pTcomp_HuFlueGas, rho - density in kg/m³
Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values:

rho_pTcomp_HuFlueGas, rho = -1·10¹⁰⁰
Reference:

Gas	ρ - ideal part	ρ - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N ₂	[26]	[28]	-
O ₂	[26]	[29]	-
CO	[26]	-	-
CO ₂	[26]	[30]	-
H ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Specific Entropy $s = f(p, h, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB::

s_phcomp_HuFlueGas

Name in Fortran:

REAL*8 FUNCTION S_PH_HUFLUEGAS (REAL*8 P, REAL*8 H, INTEGER*4 ART,
REAL*8 COMP)

Input values:

p - Pressure p in bar
h - Enthalpy h in kJ/kg
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

s_phcomp_HuFlueGas, s - specific entropy in kJ/(kg K)

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

s_phcomp_HuFlueGas, s = $-1 \cdot 10^{100}$

Reference:

Gas	h, s - ideal part	h, s - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N ₂	[26]	[28]	-
O ₂	[26]	[29]	-
CO	[26]	-	-
CO ₂	[26]	[30]	-
H ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Specific Entropy $s = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

s_pTcomp_HuFlueGas

Name in Fortran:

REAL*8 FUNCTION S_PT_HUFLUEGAS (REAL*8 P, REAL*8 T, INTEGER*4 ART,
REAL*8 COMP)

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
 comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

s_pTcomp_HuFlueGas, s - specific entropy in kJ/(kg K)

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
 Pressure p : from 0.01 bar to 1000 bar
 Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Result for incorrect input values:

s_pTcomp_HuFlueGas,s = $-1 \cdot 10^{100}$

Reference:

Gas	h,s - ideal part	h,s - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N ₂	[26]	[28]	-
O ₂	[26]	[29]	-
CO	[26]	-	-
CO ₂	[26]	[30]	-
H ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Surface tension of water $\sigma_w = f(t)$
Name in FluidEXL, FluidMAT and FluidLAB:

sigmaw_T_HuFlueGas

Name in Fortran:

```
REAL*8 FUNCTION SIGMAW_T_HUFLUEGAS (REAL*8 T, INTEGER*4 ART,  
                                     REAL*8 COMP)
```

Input values:

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

Result:

sigma_T_HuFlueGas, sigma - Surface tension of water σ_w in N/m

Range of validity:

Temperature t : from 0 °C to 647.096 °C

Comments:

Calculation for pure water from IAPWS-IF97

Result for incorrect input values:

sigma_T_HuFlueGas, Sigma = $-1 \cdot 10^{100}$

References: [8]

Temperature $t = f(h, s, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:

T_hscomp_HuFlueGas

Name in Fortran:

REAL*8 FUNCTION T_HS_HUFLUEGAS (REAL*8 H, REAL*8 S, INTEGER*4 ART,
REAL*8 COMP)

Input values:

h - Enthalpy h in kJ/kg
s - Entropy s in kJ/(kg K)
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

T_hscomp_HuFlueGas, T - Temperature t in °C

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

T_hscomp_HuFlueGas, $t = -1 \cdot 10^{100}$

Reference:

Gas	h, s - ideal part	h, s - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

Temperature $t = f(p, h, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:

T_phcomp_HuFlueGas

Name in Fortran:

REAL*8 FUNCTION T_PH_HUFLUEGAS (REAL*8 P, REAL*8 H, INTEGER*4 ART,
REAL*8 COMP)

Input values:

p - Pressure p in bar
h - Enthalpy h in kJ/kg
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

T_phcomp_HuFlueGas, T - Temperature in °C

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

T_phcomp_HuFlueGas, $t = -1 \cdot 10^{100}$

Reference:

Gas	h - ideal part	h - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

Temperature $t = f(p, s, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

T_pscomp_HuFlueGas

Name in Fortran:

REAL*8 FUNCTION T_PS_HUFLUEGAS (REAL*8 P, REAL*8 S, INTEGER*4 ART,
REAL*8 COMP)

Input values:

p - Pressure p in bar
s - Entropy s in kJ/(kg K)
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

T_pscomp_HuFlueGas, T - Temperature t in °C

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

T_pscomp_HuFlueGas, $t = -1 \cdot 10^{100}$

Reference:

Gas	h, s - ideal part	h, s - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

Dew point temperature of water $t_{w,dew} = f(p, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

Tw dew_pcomp_HuFlueGas

Name in Fortran:

```
REAL*8 FUNCTION T WDEW_P_HUFLUEGAS (REAL*8 P, INTEGER*4 ART,  
                                     REAL*8 COMP)
```

Input values:

p - Pressure p in bar

art - Type of composition:
art=1 for composition in mass fractions ξ
art=0 for composition in mole fractions ψ

comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
- Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
comp(0) - Dummy
comp(1)...comp(8) mass- or mole fractions of mixture of gases

Result:

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

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
 Pressure p : from 0.01 bar to 1000 bar
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Result for incorrect input values:

$\text{Tw dew_pcomp_HuFlueGas, Tw dew} = -1 \cdot 10^{100}$

Literatur:

$$\begin{aligned} t_s(p, p_d) & \quad \text{for } t \geq 0.01^\circ\text{C} \quad \text{from IAPWS-IF97 [1], [2], [3], [4]} \\ t_{\text{sub}}(p, p_d) & \quad \text{for } t < 0.01^\circ\text{C} \quad \text{from IAPWS-92 [24]} \end{aligned}$$

Internal Energy $u = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:

u_pTcomp_HuFlueGas

Name in Fortran:

REAL*8 FUNCTION U_PT_HUFLUEGAS (REAL*8 P, REAL*8 T, INTEGER*4 ART,
REAL*8 COMP)

Input values:

p - Pressure p in bar
t - Temperature t in °C
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

u_pTcomp_HuFlueGas, u - internal energy in kJ/kg

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values:

u_pTcomp_HuFlueGas, u = $-1 \cdot 10^{100}$

Reference:

Gas	u - ideal part	u - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N ₂	[26]	[28]	-
O ₂	[26]	[29]	-
CO	[26]	-	-
CO ₂	[26]	[30]	-
H ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Specific volume $v = f(h, s, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:

v_hscomp_HuFlueGas

Name in Fortran:

REAL*8 FUNCTION V_HS_HUFLUEGAS (REAL*8 H, REAL*8 S, INTEGER*4 ART,
REAL*8 COMP)

Input values:

h - Enthalpy h in kJ/kg
s - Entropy s in kJ/(kg K)
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ

comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

v_hscomp_HuFlueGas, v - specific volume in m³/kg

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

v_hscomp_HuFlueGas, $v = -1 \cdot 10^{100}$

Reference:

Gas	v, h, s - ideal part	v, h, s - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

Specific volume $v = f(p, h, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:

v_phcomp_HuFlueGas

Name in Fortran:

REAL*8 FUNCTION V_PH_HUFLUEGAS (REAL*8 P, REAL*8 H, INTEGER*4 ART,
REAL*8 COMP)

Input values:

p - Pressure p in bar
h - Enthalpy h in kJ/kg
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

v_phcomp_HuFlueGas, v - specific volume in m³/kg

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

v_phcomp_HuFlueGas, $v = -1 \cdot 10^{100}$

Reference:

Gas	v, h - ideal part	v, h - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

Specific volume $v = f(p, s, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:

v_pscomp_HuFlueGas

Name in Fortran:

REAL*8 FUNCTION V_PS_HUFLUEGAS (REAL*8 P, REAL*8 S, INTEGER*4 ART,
REAL*8 COMP)

Input values:

p - Pressure p in bar
s - Entropy s in kJ/(kg K)
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

v_pscomp_HuFlueGas, v - specific volume in m³/kg

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Calculation:

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

Result for incorrect input values:

v_pscomp_HuFlueGas, $v = -1 \cdot 10^{100}$

Reference:

Gas	v, s - ideal part	v, s - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

Specific volume $v = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:

v_pTcomp_HuFlueGas

Name in Fortran:

REAL*8 FUNCTION V_PT_HUFLUEGAS (REAL*8 P, REAL*8 T, INTEGER*4 ART,
REAL*8 COMP)

Input values:

p - Pressure p in bar
t - Temperature t in °C
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

v_pTcomp_HuFlueGas, v - specific volume in m³/kg

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

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

Result for incorrect input values:

v_pTcomp_HuFlueGas, $v = -1 \cdot 10^{100}$

Reference:

Gas	v - ideal part	v - real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N ₂	[26]	[28]	-
O ₂	[26]	[29]	-
CO	[26]	-	-
CO ₂	[26]	[30]	-
H ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Specific volume $v = f(t, s, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$
Name in FluidEXL, FluidMAT and FluidLAB:

v_Tscomp_HuFlueGas

Name in Fortran:

REAL*8 FUNCTION V_TS_HUFLUEGAS (REAL*8 T, REAL*8 S, INTEGER*4 ART,
REAL*8 COMP)

Input values:

t - Temperature t in °C
s - Entropy s in kJ/(kg K)
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

v_Tscomp_HuFlueGas, v - Specific volume in m³/kg

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

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

Calculation:

- for unsaturated and saturated humid gas ($\psi_w \leq \psi_{w, \text{sat}}$) as ideal mixture of real gases (dry gas and steam)
- for fog ($\psi_w > \psi_{w, \text{sat}}$) as ideal mixture of saturated humid gas and liquid water or water ice, no calculation for liquid-ice fog at 0.01 °C

Result for incorrect input values:

v_Tscomp_HuFlueGas, $v = -1 \cdot 10^{100}$

Reference:

Gas	v, h, s ideal part	v, h, s real part	ice
Ar	[26]	[27]	-
Ne	[26]	-	-
N ₂	[26]	[28]	-
O ₂	[26]	[29]	-
CO	[26]	-	-
CO ₂	[26]	[30]	-
H ₂ O	[26]	[31]	[25]
SO ₂	[26]	-	-

Speed of sound $w = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

w_pTcomp_HuFlueGas

Name in Fortran:

REAL*8 FUNCTION W_PT_HUFLUEGAS (REAL*8 P, REAL*8 T, INTEGER*4 ART,
REAL*8 COMP)

Input values:

p - Pressure p in bar
 t - Temperature t in °C
 art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
 comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

w_pTcomp_HuFlueGas, w - speed of sound in m/s

Range of validity:

Temperature t : from - 70 °C to 3000.00°C
 Pressure p : from 0.01 bar to 1000 bar
 Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol
 Partial pressures of CO₂ and SO₂ less than saturation pressures

Comments:

Calculation:

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

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

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

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

Result for incorrect input values:

w_pTcomp_HuFlueGas, w = -1.10¹⁰⁰

Reference:

Gas	v, c_p, c_v - ideal part	v, c_p, c_v - real part
Ar	[26]	[27]
Ne	[26]	-
N ₂	[26]	[28]
O ₂	[26]	[29]
CO	[26]	-
CO ₂	[26]	[30]
H ₂ O	[26]	[31]
SO ₂	[26]	-

Humidity ratio (Absolute humidity) $x_w = f(\xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

xw_comp_HuFlueGas

Name in Fortran:

REAL*8 FUNCTION XW_HUFLUEGAS (INTEGER*4 ART, REAL*8 COMP)

Input values:

art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ

comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

xw_comp_HuFlueGas, xw - Absolute humidity in gWater / kgGas

Range of validity:

Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol

Comments:

$$\text{Absolute humidity of water } x_w = \frac{\psi_w}{\frac{R_w}{R_{\text{mix}}} - \psi_w}$$

Result for incorrect input values:

xw_comp_HuFlueGas, xw = $-1 \cdot 10^{100}$

Mole fraction of liquid water $\psi_{wl} = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

psiwl_pTcomp_HuFlueGas

Name in Fortran:

```
REAL*8 FUNCTION PSIWL_PT_HUFLUEGAS (REAL*8 P, REAL*8 T, INTEGER*4
ART,
REAL*8 COMP)
```

Input values:

p - Pressure p in bar
t - Temperature t in °C
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

psiwl_pTcomp_HuFlueGas, psiwl - Mole fraction of water in kmol/kmol

Range of validity:

Temperature t : $t_{\tau}(p, \text{comp}) \leq t \leq t_s(p, p_d)$
 (t_s – Boiling temperature of water in gas mixtures)
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol

Comments:

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

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

with $p_{dsat}(p, t)$ for $t \geq 0.01$ °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_HuFlueGas, psiwl = $-1 \cdot 10^{100}$

Reference:

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

Mole fraction of water of sat. gas $\psi_{w,sat} = f(p, t, \xi_1 \dots \xi_8 \text{ or } \psi_1 \dots \psi_8)$

Name in FluidEXL, FluidMAT and FluidLAB:

psiwsat_pTcomp_HuFlueGas

Name in Fortran:

```
REAL*8 FUNCTION PSIWSAT_PT_HUFLUEGAS (REAL*8 P, REAL*8 T,
                                         INTEGER*4 ART, REAL*8 COMP)
```

Input values:

p - Pressure p in bar
t - Temperature t in °C
art - Type of composition:
 art=1 for composition in mass fractions ξ
 art=0 for composition in mole fractions ψ
comp(0:8) - Composition in mass fractions $\xi_1 \dots \xi_8$ in kg/kg with art=1
 - Composition in mole fractions $\psi_1 \dots \psi_8$ in kmol/kmol with art=0
 comp(0) - Dummy
 comp(1)...comp(8) mass-or mole fractions of mixture of gases

Result:

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

Range of validity:

Temperature t : - $70\text{ °C} \leq t \leq t_s(p, p_d)$
 (t_s – Boiling temperature of water in gas mixtures)
Pressure p : from 0.01 bar to 1000 bar
Mole fraction of water ψ_w : from 0 kmol/kmol to 0.99 kmol/kmol

Comments:

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

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

Result for incorrect input values:

psiwsat_pTcomp_HuFlueGas, psiwsat = $-1 \cdot 10^{100}$

Reference:

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

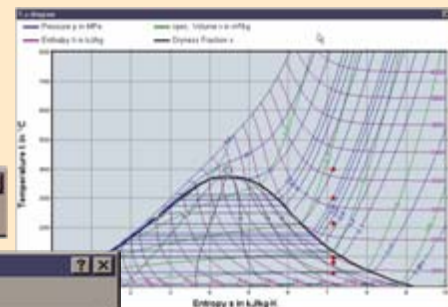
**4. Property Libraries for Calculating Heat Cycles, Boilers, and Turbines**

Water and Steam	Humid Combustion Gases	Humid Air
Library LibIF97 - Industrial Formulation IAPWS-IF97 - Supplementary Standards - IAPWS-IF97-S01 - IAPWS-IF97-S03rev - IAPWS-IF97-S04 - IAPWS-IF97-S05	Library LibIdGas Ideal gas mixture (VDI-Guideline 4670) Library LibHuGas Ideal mixture of the real fluids: CO ₂ - Span and Wagner O ₂ - Schmidt and Wagner H ₂ O - IAPWS-95 Ar - Tegeler et al. N ₂ - Span et al. and of the ideal gases: SO ₂ , CO, Ne (scientific equations of Bucker et al.) Consideration of Dissociation from VDI 4670 and Poynting effect	Library LibIdAir Ideal gas mixture (VDI-Guideline 4670) Library LibAirWa Ideal mixture of the real fluids: - dry air: Lemmon et al. - steam and water: IAPWS-95 Consideration of - Dissociation from VDI-Guideline 4670 - Poynting effect

Carbon Dioxide	Ideal Gas Mixture	Refrigerants
Library LibCO2 Formulation of Span and Wagner	Library LibIdGasMix Ideal mixture of the ideal gases: Ar Air OH Ethylene Ne NO He Propylene N ₂ H ₂ O F ₂ Propane O ₂ SO ₂ NH ₃ Iso-Butane CO H ₂ Methane n-Butane CO ₂ H ₂ S Ethane Benzene Methanol	Ammonia Library LibNH3 R134a Library LibR134a Propane Library LibPropane Iso-Butane Library LibButane_Iso n-Butane Library LibButane_n
Hydrogen	Mixtures in Absorption Processes Ammonia & Water Library LibAmWa Water & Lithium Bromide Library LibWaLi	
Library LibH2 Formulation of Younglove		
Helium		
Library LibHe Formulation of McCarty		

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

The Add-In FluidEXL^{Graphics} has been developed for calculating thermophysical properties in Excel[®]. Using the Add-In, a direct call of the functions from the property libraries is possible. The calculated properties can be shown in thermodynamic charts.

**Thermodynamic Charts:**

- h-s diagram
- T-s diagram
- log p-h diagram
- log p-log v diagram
- log p-T diagram
- p-T diagram
- T-h diagram
- T-log v diagram
- log p-s diagram
- h-log v diagram
- s-log v diagram
- h-x diagram for humid air

Library FluidMAT for Mathcad®

Using the interface FluidMAT, the functions of property libraries can be called in Mathcad®.

Calculation of the Enthalpy of Steam from the IAPWS-IF97

$p := 10$ bar given pressure
 $t := 300$ °C given temperature
 $x := -1$ $\frac{\text{kg}}{\text{kg}}$ vapor fraction (-1 for single phase region)

$h := h_ptx_97(p, t, x)$ call of the function from FluidMAT

$h = 3051.70$ $\frac{\text{kJ}}{\text{kg}}$ result for enthalpy

Library FluidLAB for MATLAB®

MATLAB 7.3.0 (R2006a)

Current Directory: C:\Programme\FuildLAB\Example

File List:

File Name	File Type	Description
h_ptx_Huak.m	MEX-file	
LibHuak.dll	DLL File	
libhuakmex.dll	DLL File	
libhuakmex.m	DLL File	
libhuakmex.m	DLL File	
libhuakmex.m	DLL File	
Example_h_ptx_Huak.m	M-file	h_ptx_Huak.m

Workspace: Current Directory

Command Window:

```

>> h = h_ptx_Huak(p,t,x)
h =
    3051.700
    
```

Software for Pocket Calculators

Software for calculating thermodynamic and transport properties for

- Water and steam
- Combustion Gases and
- Humid air

has been developed for these pocket calculators.

FluidHP
HP 48 HP 49

FluidTI
TI 83
TI 84
TI 89
TI Voyage 200
TI 92

FluidCasio
CFX-9850
ALGEBRA FX 2.0

Example: Calculation of the Enthalpy of Steam Using FluidTI

Function: $h = f(p, t, x)$

Help

About Fluid

Enter=OK

Choice of the function $h = f(p, t, x)$

Specific enthalpy $h = f(p, t, x)$

Input of parameter

p [MPa] :

t [°C] :

x [kg/kg] :

Enter=OK

Input of the parameters p , t and x

Result

$h = 3097.38$ kJ/kg

save as :

Enter=OK

Result for enthalpy

The following thermodynamic and transport properties can be calculated:

Thermodynamic Properties

- Saturation 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

Thermodynamic Derivatives

- All partial derivatives can be calculated

Transport Properties

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

Backward Functions

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

For information please contact:

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 Fax : +49-3583-61-1846

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6 Sales List

Date: June 2007

The following companies and institutions use the property libraries:

Gerb, Dresden, Germany	June 1997
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M&M Turbine Technique, Bielefeld, Germany	June 1998, January 2000, January 2001, September 2001, June 2006
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Alfa Engineering Company, Switzerland	September 1998
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University of Applied Sciences of Regensburg, Germany	April 1999
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Engineering Company Ostendorf, Gummersbach, Germany	December 1999, May 2003
SOFBID Information Systems, Zwingenberg, Germany (general license for program EBSILON)	January 2000 June 2002, May 2003, April 2004
AG KKK - PGW Turbo, Leipzig, Germany	January 2000

PREUSSAG NOELL, Würzburg, Germany	January 2000, March 2001
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GK Hannover	March 2000
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Pape	April 2000, January 2006
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energeticals (e-concept) Munich, Germany	November 2004

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