

# **Property Library for Gas Mixtures in the Energy-Technological Process Modelling**

**FluidVIEW  
with LibIdGasMix  
for LabVIEW™**

Prof. Hans-Joachim Kretzschmar  
Dr. Sebastian Herrmann  
Dr. Matthias Kunick  
K. Knobloch  
B. Nowak

# **Property Library of Ammonia-Water Mixtures**

## **Including DLL and Add-on for LabVIEW™**

### **FluidVIEW**

### **LibIdGasMix**

## **Contents**

0. Package Contents
  - 0.1 Zip-files for 32-bit LabVIEW™
  - 0.2 Zip-files for 64-bit LabVIEW™
1. Property Functions
2. Application of FluidVIEW in LabVIEW™
  - 2.1 Installing FluidVIEW
  - 2.2 The FluidVIEW Help System
  - 2.3 Licensing the LibIdGasMix Property Library
  - 2.4 Example calculation
  - 2.5 Removing FluidVIEW
3. Program Documentation for Mixed Gases (imix-Functions)
4. Program Documentation for Single Gases (igas-Functions)
5. Property Libraries for Calculating Heat Cycles, Boilers, Turbines, and Refrigerators
6. References
7. Satisfied Customers

---

© KCE-ThermoFluidProperties  
Professor Hans-Joachim Kretzschmar  
Wallotstr. 3, 01307 Dresden, Germany  
Phone: +49-351-27597860  
Mobile: +49-172-7914607  
Fax: +49-3222-1095810  
Email: [info@thermofluidprop.com](mailto:info@thermofluidprop.com)  
Internet: [www.thermofluidprop.com](http://www.thermofluidprop.com)

# 0 Package Contents

## 0.1 Zip files for 32-bit LabVIEW™

In order to install FluidVIEW on a computer running a 32-bit version of LabVIEW™ the zip file **CD\_FluidVIEW\_LibIdGasMix.zip** is delivered. The directory structure of the archive is corresponding to the default directory of LabVIEW™.

The effects of the fifteen files, which are stored in the different directories of the zip archive, are shown in the Tables 0.1, 0.2, 0.3 and 0.4.

**Table 0.1** Effects of the files located in the archive directory **CD\_FluidVIEW\_LibIdGasMix\vi.lib\FluidVIEW\LibIdGasMix**

Filename	Effects
LibIdGasMix.llb	LabVIEW™ library file, containing every function of the LibIdGasMix property library in the form of subprograms (SubVIs)

**Table 0.2** Effects of the files located in the archive directory **CD\_FluidVIEW\_LibIdGasMix\menus\Categories\FluidVIEW**

Filename	Effects
dir.mnu	The palette view of LabVIEW™ is based on the palette files (*.mnu). They include the palette data (e. g. the display name, the palette icon, the palette description, the help information, the synchronize information and the items)

**Table 0.3** Effects of the files located in the archive directory **CD\_FluidVIEW\_LibIdGasMix\source**

Filename	Effects
LibIdGasMix.dll	Dynamic-link library containing the algorithms for the calculation of the property functions of carbon dioxide
advapi32.dll	Runtime library
Dformd.dll	Runtime library for the Fortran DLL
Dforrt.dll	Runtime library for the Fortran DLL
LC.dll	Auxiliary library
msvcp60.dll	Runtime library
msvcrt.dll	Runtime library

**Table 0.4** Effects of the files located in the archive directory **CD\_FluidVIEW\_LibIdGasMix\help \FluidVIEW-help**

Filename	Effects
FluidVIEW_LibIdGasMix.pdf	User's guide of the property library LibIdGasMix for the LabVIEW™ Add-On FluidVIEW
LibIdGasMix.chm	Help file with descriptions for each function
OpenLibIdGasMix_doc.vi	LabVIEW™ instrument to open the user's guide via the help menu
LibIdGasMix.txt	Text file to change the name of the menu item of the help file
OpenLibIdGasMix_doc.txt	Text file to change the name of the menu item of the file OpenLibIdGasMix_doc.vi

## 0.2 Zip files for 64-bit LabVIEW™

In order to install FluidVIEW on a computer running a 64-bit version of LabVIEW™ the zip file **CD\_FluidVIEW\_LibIdGasMix\_x64.zip** is delivered. The directory structure of the archive is corresponding to the default directory of LabVIEW™.

The effects of the fifteen files, which are stored in the different directories of the zip archive, are shown in the Tables 0.5, 0.6, 0.7, 0.8 and 0.9.

**Table 0.5** Effects of the files located in the archive directory **CD\_FluidVIEW\_LibIdGasMix\_x64\vi.lib \FluidVIEW\LibIdGasMix**

Filename	Effects
LibIdGasMix.llb	LabVIEW™ library file, containing every function of the LibIdGasMix property library in the form of subprograms (SubVIs)

**Table 0.6** Effects of the files located in the archive directory **CD\_FluidVIEW\_LibIdGasMix\_x64\menus \Categories\FluidVIEW**

Filename	Effects
dir.mnu	The palette view of LabVIEW™ is based on the palette files (*.mnu). They include the palette data (e. g. the display name, the palette icon, the palette description, the help information, the synchronize information and the items)

**Table 0.7** Effects of the files located in the archive directory **CD\_FluidVIEW\_LibIdGasMix\_x64\source**

Filename	Effects
LibIdGasMix.dll	Dynamic-link library containing the algorithms for the calculation of the property functions of carbon dioxide
Capt_ico_big.ico	Icon file
Libmmd.dll	Runtime library
Libifcoremd.dll	Runtime library
LC.dll	Auxiliary library
Libiomp5md.dll	Runtime library

**Table 0.8** Effects of the files located in the archive directory **CD\_FluidVIEW\_LibIdGasMix\_x64\help\FluidVIEW-help**

Filename	Effects
FluidVIEW_LibIdGasMix.pdf	User's guide of the LibIdGasMix property library for the LabVIEW™ Add-On FluidVIEW
LibIdGasMix.chm	Help file with descriptions for each function
OpenLibIdGasMix_doc.vi	LabVIEW™ instrument to open the user's guide via the help menu
LibIdGasMix.txt	Text file to change the name of the menu item of the help file
OpenLibIdGasMix_doc.txt	Text file to change the name of the menu item of the file OpenLibIdGasMix_doc.vi

**Table 0.9** Effects of the files located in the archive directory **CD\_FluidVIEW\_LibIdGasMix\_x64\vcredist\_x64**

Filename	Effects
vcredist_x64.exe	Executable file to install the Microsoft Visual C++ 2008 Redistributable Package (x64). Within runtime components of Visual C++ Libraries required to run 64-bit applications developed with Visual C++ on a computer that does not have Visual C++ 2010 installed.

# 1. Property Functions

## 1.1 Gases of the library

**Table 1.** Gases and algorithms for the calculation of thermodynamic properties.

Gas no.	Gas / component		Algorithm, bibliographic reference
1	Ar	Argon	VDI 4670 [21]
2	Ne	Neon	VDI 4670 [21]
3	N <sub>2</sub>	Nitrogen	VDI 4670 [21]
4	O <sub>2</sub>	Oxygen	VDI 4670 [21]
5	CO	Carbon monoxide	VDI 4670 [21]
6	CO <sub>2</sub>	Carbon dioxide	VDI 4670 [21]
7	H <sub>2</sub> O	Steam	VDI 4670 [21]
8	SO <sub>2</sub>	Sulfur dioxide	VDI 4670 [21]
9	AIR	Air (dry)	Mixture, VDI 4670 <sup>1)</sup> [21]
10	AIR-N <sub>2</sub>	Air nitrogen	Mixture, VDI 4670 <sup>2)</sup> [21]
11	NO	Nitrogen oxide	NASA [40]
12	H <sub>2</sub> S	Sulfur hydrogen	Span, Lemmon [41]
13	OH	Hydroxyl	NASA [40]
14	CH <sub>3</sub> OH	Methanol	IUPAC [26]
15	CH <sub>4</sub>	Methane	IUPAC [27]
16	C <sub>2</sub> H <sub>4</sub>	Ethylene	IUPAC [35]
17	C <sub>2</sub> H <sub>6</sub>	Ethane	Buecker [29]
18	C <sub>3</sub> H <sub>6</sub>	Propylene	Overhoff [42]
19	C <sub>3</sub> H <sub>8</sub>	Propane	Lemmon [43]
20	n-C <sub>4</sub> H <sub>10</sub>	n-Butane	Buecker [29]
21	Iso-C <sub>4</sub> H <sub>10</sub>	Iso-Butane	Buecker [29]
22	C <sub>6</sub> H <sub>6</sub>	Benzene	Polt [44]
23	H <sub>2</sub>	Hydrogen	Leachman [45]
24	He	Helium	GERG [46]
25	NH <sub>3</sub>	Ammonia	Tillner-Roth [38]/ NASA [40] <sup>3)</sup>
26	free <sup>4)</sup>		
27	free <sup>4)</sup>		
28	free <sup>4)</sup>		
29	free <sup>4)</sup>		
30	F <sub>2</sub>	Fluorine <sup>5)</sup>	IUPAC [28]

<sup>1)</sup> Composition of dry air

Mole fractions	78.1109 % N <sub>2</sub>	20.9548 % O <sub>2</sub>	0.9343 % Ar
Mass fractions	75.5577 % N <sub>2</sub>	23.1535 % O <sub>2</sub>	1.2888 % Ar

<sup>2)</sup> Composition of air nitrogen

Mole fractions	98.8180 % N <sub>2</sub>	1.1820 % Ar
Mass fractions	98.3229 % N <sub>2</sub>	1.6771 % Ar

- 3) Thermodynamic properties of ammonia are calculated on the algorithms corresponding to *Tillner-Roth* [38] to a temperature of 1273.15 °C. Equations of NASA [40] are applied when calculating with temperatures which are higher than 1273.15 °C. Data are smoothed between temperatures ranging from 1273.15 °C to 2273.15 °C.
- 4) The gas numbers 26 to 29 are currently not defined.
- 5) Due to its chemical properties, fluorine can not be calculated as a mixture gas but as a single gas.

**Table 2.** Gases and algorithms for the calculation of transport properties.

Gas no.	Mixture gas		Algorithm, bibliographic reference
1	Ar	Argon	Brandt [15]
2	Ne	Neon	Brandt [15]
3	N <sub>2</sub>	Nitrogen	Brandt [15]
4	O <sub>2</sub>	Oxygen	Brandt [15]
5	CO	Carbon monoxide	Brandt [15]
6	CO <sub>2</sub>	Carbon dioxide	Brandt [15]
7	H <sub>2</sub> O	Steam	Brandt [15]
8	SO <sub>2</sub>	Sulfur dioxide	Brandt [15]
9	AIR	Air (dry)	Brandt [15]
10	AIR-N <sub>2</sub>	Air nitrogen	Brandt [15]
11	NO	Nitrogen oxide	Brandt [15]
12	H <sub>2</sub> S	Sulfur hydrogen	Brandt [15]
13	OH	Hydroxyl	- <sup>6)</sup>
14	CH <sub>3</sub> OH	Methanol	VB [33]
15	CH <sub>4</sub>	Methane	Brandt [15]
16	C <sub>2</sub> H <sub>4</sub>	Ethylene	VB [33]
17	C <sub>2</sub> H <sub>6</sub>	Ethane	Brandt [15]
18	C <sub>3</sub> H <sub>6</sub>	Propylene	VB [33]
19	C <sub>3</sub> H <sub>8</sub>	Propane	Brandt [15]
20	C <sub>4</sub> H <sub>10</sub>	n-Butane	VB [33]
21	C <sub>4</sub> H <sub>10</sub>	Iso-Butane	VB [33]
22	C <sub>6</sub> H <sub>6</sub>	Benzene	VB [33]
23	H <sub>2</sub>	Hydrogen	Brandt [15]
24	He	Helium	Brandt [15]
25	NH <sub>3</sub>	Ammonia	Brandt [15]
26 to 29	free		
30	F <sub>2</sub>	Fluorine	VB [33]

- 6) Regarding hydroxyl OH, there are no algorithms for the transport properties. The following details are valid for mixtures with the gas hydroxyl:

Mass fraction up to 10% OH	→ when calculating transport properties the fraction of OH is not considered
Mass fraction from 10% up to 100%	→ Error message -130666

## 1.2 Property Functions for Ideal Gas Mixtures (igmix-Functions)

Property function	Function Name	Call from Fortran	Property or function	Unit of the value calculated	Details
$a = f(p,t,type,\xi_1\dots\xi_{30} \text{ or } \psi_1\dots\psi_{30})$	a_pt_igmix	A_PT_IGMIX(P,T,TYPE,COMP(0:30)) C_A_PT_IGMIX (A_P,T,TYPE,COMP(0:30))	Thermal diffusivity of the mixture	m <sup>2</sup> /s	3/1
$c_p = f(p,t,type,\xi_1\dots\xi_{30} \text{ or } \psi_1\dots\psi_{30})$	cp_pt_igmix	CP_PT_IGMIX(P,T,TYPE,COMP(0:30)) C_CP_PT_IGMIX (CP_P,T,TYPE,COMP(0:30))	Isobaric heat capacity of the mixture	kJ/(kg K)	3/2
$c_v = f(p,t,type,\xi_1\dots\xi_{30} \text{ or } \psi_1\dots\psi_{30})$	cv_pt_igmix	CV_PT_IGMIX(P,T,TYPE,COMP(0:30)) C_CV_PT_IGMIX(CV_P,T,TYPE,COMP(0:30))	Isochoric heat capacity of the mixture	kJ/(kg K)	3/3
$\eta = f(p,t,type,\xi_1\dots\xi_{30} \text{ or } \psi_1\dots\psi_{30})$	eta_pt_igmix	ETA_T_IGMIX(P,T,TYPE,COMP(0:30)) C_ETA_T_IGMIX(ETA_P,T,TYPE,COMP(0:30))	Dynamic viscosity of the mixture	Pa s = kg/(m s)	3/4
$h = f(p,t,type,\xi_1\dots\xi_{30} \text{ or } \psi_1\dots\psi_{30})$	h_pt_igmix	H_PT_IGMIX(P,T,TYPE,COMP(0:30)) C_H_PT_IGMIX(P,T,TYPE,COMP(0:30))	Enthalpy of the mixture	kJ/kg	3/5
$\kappa = f(p,t,type,\xi_1\dots\xi_{30} \text{ or } \psi_1\dots\psi_{30})$	kappa_pt_igmix	KAPPA_PT_IGMIX(P,T,TYPE,COMP(0:30)) C_KAPPA_PT_IGMIX(KAPPA_P,T,TYPE,COMP(0:30))	Isentropic exponent of the mixture		3/6
$\lambda = f(p,t,type,\xi_1\dots\xi_{30} \text{ or } \psi_1\dots\psi_{30})$	lambda_pt_igmix	LAMBDA_T_IGMIX(P,T,TYPE,COMP(0:30)) C_LAMBDA_T_IGMIX(LAMBDA_P,T,TYPE,COMP(0:30))	Thermal conductivity of the mixture	W/(m K)	3/7
$M = f(type,\xi_1\dots\xi_{30} \text{ or } \psi_1\dots\psi_{30})$	M_igmix	M_IGMIX(TYPE,COMP(0:30)) C_M_IGMIX(M,TYPE,COMP(0:30))	Molar mass of the mixture	kg/kmol	3/8
$\nu = f(p,t,type,\xi_1\dots\xi_{30} \text{ or } \psi_1\dots\psi_{30})$	ny_pt_igmix	NY_PT_IGMIX(P,T,TYPE,COMP(0:30)) C_NY_PT_IGMIX(NY_P,T,TYPE,COMP(0:30))	Kinematic viscosity of the mixture	m <sup>2</sup> /s	3/9
$p = f(p,t,type,\xi_1\dots\xi_{30} \text{ or } \psi_1\dots\psi_{30})$	p_ts_igmix	P_TS_IGMIX(T,S,TYPE,COMP(0:30)) C_P_TS_IGMIX(P,T,S,TYPE,COMP(0:30))	Backward function: Mixture pressure from temperature and entropy	bar	3/10

Property function	Function Name	Call from Fortran	Property or function	Unit of the value calculated	Details
$p = f(t, v, \text{type}, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$	p_tv_igmix	P_TV_IGMIX(T,V,TYPE,COMP(0:30)) C_P_TV_IGMIX(P,T,V,TYPE,COMP(0:30))	Backward function: Mixture pressure from temperature and specific volume	bar	3/11
$Pr = f(p, t, \text{type}, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$	Pr_pt_igmix	PR_PT_IGMIX(P,T,TYPE,COMP(0:30)) C_PR_PT_IGMIX(PR,P,T,TYPE,COMP(0:30))	Prandtl number of the mixture		3/12
$\psi_i = f(\text{igas}, \xi_1 \dots \xi_{30})$	psi_igas_xsi_igmix	PSI_IGAS_XSI_IGMIX(IGAS,XSI(0:30)) C_PSI_IGAS_XSI_IGMIX(PSI,IGAS,XSI(0:30))	Mole fraction of the gas igas from the mass fractions of all components	kmol/kmol	3/13
$R = f(\text{type}, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$	R_igmix	R_IGMIX(TYPE,COMP(0:30)) C_R_IGMIX(R,TYPE,COMP(0:30))	Specific gas constant of the mixture	kJ/(kg K)	3/14
$\rho = f(p, t, \text{type}, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$	rho_pt_igmix	RHO_PT_IGMIX(P,T,COMP(0:30)) C_RHO_PT_IGMIX(RHO,P,T,COMP(0:30))	Density of the mixture	kg/m³	3/15
$s = f(p, t, \text{type}, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$	s_pt_igmix	S_PT_IGMIX(P,T,TYPE,COMP(0:30)) C_S_PT_IGMIX(S,P,T,TYPE,COMP(0:30))	Entropy of the mixture	kJ/(kg K)	3/16
$t = f(p, h, \text{type}, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$	t_ph_igmix	T_PH_IGMIX(P,H,TYPE,COMP(0:30)) C_T_PH_IGMIX(T,P,H,TYPE,COMP(0:30))	Backward function: Temperature from mixture pressure and enthalpy	°C	3/17
$t = f(p, s, \text{type}, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$	t_ps_igmix	T_PS_IGMIX(P,S,TYPE,COMP(0:30)) C_T_PS_IGMIX(T,P,S,TYPE,COMP(0:30))	Backward function: Temperature from mixture pressure and entropy	°C	3/18
$t = f(p, v, \text{type}, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$	t_pv_igmix	T_PV_IGMIX(P,V, IGAS) C_T_PV_IGMIX(T,P,V, IGAS)	Backward function: Temperature from mixture pressure and specific volume	°C	3/19

Property function	Function Name	Call from Fortran	Property or function	Unit of the value calculated	Details
$u = f(p,t,\text{type},\xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$	u_pt_igmix	U_PT_IGMIX(P,T, IGAS) C_U_PT_IGMIX(U,P,T, IGAS)	Internal energy of the mixture	kJ/kg	3/20
$v = f(p,t,\text{ttype},\xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$	v_pt_igmix	V_PT_IGMIX(P,T,TYPE,COMP(0:30)) C_V_PT_IGMIX(V,P,T,TYPE,COMP(0:30))	Specific volume of the mixture	m <sup>3</sup> /kg	3/21
$w = f(p,t,\text{type},\xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$	w_pt_igmix	W_PT_IGMIX(P,T,TYPE,COMP(0:30)) C_W_PT_IGMIX(W,P,T,TYPE,COMP(0:30))	Isentropic speed of sound of the mixture	m/s	3/22
$\xi_i = f(\text{igas}, \psi_1 \dots \psi_{30})$	xsi_igas_psi_igmix	XSI_IGAS_PSI_IGMIX(IGAS,PSI(0:30)) C_XSI_IGAS_PSI_IGMIX(XSI,IGAS,PSI(0:30))	Mass fraction of the gas igas from the mole fractions of all components	kg/kg	3/23

## Units

Symbol	Name	Unit
T	Temperature	°C
p	Total pressure	bar
$\xi_1 \dots \xi_{30}$	Mass fractions of the mixture gases	kg/kg
$\psi_1 \dots \psi_{30}$	Mole fractions/volume fractions of the mixture gases	kmol/kmol
type	Input parameter: type = 1 for the composition as mass fractions $\xi_1, \dots, \xi_{30}$ type = 0 for the composition as mole fractions $\psi_1, \dots, \psi_{30}$	
comp(0:30) for type =1	Composition as mass fractions $\xi_1, \dots, \xi_{30}$	kg/kg
comp(0:30) for type =0	Composition as mole fractions $\psi_1, \dots, \psi_{30}$	kmol/kmol

## Reference states:

Property	Gases (except steam)	Steam
Pressure	1.01325 bar	0.006112127 bar
Temperature	0 °C	0 °C
Enthalpy	0 kJ/kg	2500.9342 kJ/kg
Entropy	0 kJ/(kg K)	9.15591 kJ/(kg K)

## Types of variables for the function call from the LibIgGasMix DLL:

All functions	Real*8
Variable p, T, v, h, s	Real*8
Variable comp(1..30)	Real*8
Variable type, i	Integer*4

### 1.3 Property Functions for Single Ideal Gases (igas-Functions)

Property function	Function Name	Call from Fortran	Property or function	Unit of the value calculated	Details
$a = f(p,t,igas)$	a_pt_igas	A_PT_IGAS(P,T,IGAS) C_A_PT_IGAS(A,P,T, IGAS)	Thermal diffusivity of the gas igas	m <sup>2</sup> /s	4/1
$c_p = f(p,t,igas)$	cp_pt_igas	CP_PT_IGAS(P,T, IGAS) C_CP_PT_IGAS(CP,P,T, IGAS)	Isobaric heat capacity of the gas igas	kJ/(kg K)	4/2
$c_v = f(p,t,igas)$	cv_pt_igas	CV_PT_IGAS(P,T, IGAS) C_CV_PT_IGAS(CV,P,T, IGAS)	Isochoric heat capacity of the gas igas	kJ/(kg K)	4/3
$\eta = f(p,t,igas)$	eta_pt_igas	ETA_T_IGAS(P,T, IGAS) C_ETA_T_IGAS(ETA,P,T,IGAS)	Dynamic viscosity of the gas igas	Pa s = kg/(m s)	4/4
$h = f(p,t,igas)$	h_pt_igas	H_PT_IGAS(P,T, IGAS) C_H_PT_IGAS(P,T, IGAS)	Enthalpy of the gas igas	kJ/kg	4/5
$\kappa = f(p,t,igas)$	kappa_pt_igas	KAPPA_PT_IGAS(P,T IGAS) C_KAPPA_PT_IGAS(KAPPA,P,T IGAS)	Isentropic exponent of the gas igas		4/6
$\lambda = f(p,t,igas)$	lambda_pt_igas	LAMBDA_T_IGAS(P,T, IGAS) C_LAMBDA_T_IGAS(LAMBDA,P,T, IGAS)	Thermal conductivity of the gas igas	W/(m K)	4/7
$M = f(igas)$	M_igas	M_IGAS(IGAS) C_M_IGAS(M,IGAS)	Molar mass of the gas igas	kg/kmol	4/8
$\nu = f(p,t,igas)$	ny_pt_igas	NY_PT_IGAS(P,T, IGAS) C_NY_PT_IGAS(NY,P,T, IGAS)	Kinematic viscosity of the gas igas	m <sup>2</sup> /s	4/9
$p = f(t,s,igas)$	p_ts_igas	P_TS_IGAS(T,S, IGAS) C_P_TS_IGAS(P,T,S, IGAS)	Backward function: Pressure from temperature and entropy of the gas igas	bar	4/10
$p = f(t,v,igas)$	p_tv_igas	P_TV_IGAS(T,V, IGAS) C_P_TV_IGAS(P,T,V, IGAS)	Backward function: Pressure from temperature and specific volume of the gas igas	bar	4/11

Property function	Function Name	Call from Fortran	Property or function	Unit of the value calculated	Details
$Pr = f(p,t,igas)$	Pr_pt_igas	PR_PT_IGAS(P,T, IGAS) C_PR_PT_IGAS(PR,P,T, IGAS)	Prandtl number of the gas igas		4/12
$R = f(igas)$	R_igas	R_IGAS(IGAS) C_R_IGAS(R,IGAS)	Specific gas constant of the gas igas	kJ/(kg K)	4/13
$\rho = f(p,t,igas)$	rho_pt_igas	RHO_PT_IGAS(P,T, IGAS) C_RHO_PT_IGAS(RHO,P,T, IGAS)	Density of the gas igas	kg/m <sup>3</sup>	4/14
$s = f(p,t,igas)$	s_pt_igas	S_PT_IGAS(P,T, IGAS) C_S_PT_IGAS(S,P,T, IGAS)	Entropy of the gas igas	kJ/(kg K)	4/15
$t = f(p,h,igas)$	t_ph_igas	T_PH_IGAS(P,H, IGAS) C_T_PH_IGAS(T,P,H, IGAS)	Backward function: Temperature from pressure and enthalpy of the gas igas	°C	4/16
$t = f(p,s,igas)$	t_ps_igas	T_PS_IGAS(P,S, IGAS) C_T_PS_IGAS(T,P,S, IGAS)	Backward function: Temperature from pressure and entropy of the gas igas	°C	4/17
$t = f(p,v,igas)$	t_pv_igas	T_PV_IGAS(P,V, IGAS) C_T_PV_IGAS(T,P,V, IGAS)	Backward function: Temperature from pressure and specific volume of the gas igas	°C	4/18
$u = f(p,t,igas)$	u_pt_igas	U_PT_IGAS(P,T, IGAS) C_U_PT_IGAS(U,P,T, IGAS)	Specific internal energy of the gas igas	kJ/kg	4/19
$v = f(p,t,igas)$	v_pt_igas	V_PT_IGAS(P,T, IGAS) C_V_PT_IGAS(V,P,T, IGAS)	Specific volume of the gas igas	m <sup>3</sup> /kg	4/20
$w = f(p,t,igas)$	w_pt_igas	W_PT_IGAS_SI(P,T, IGAS) C_W_PT_IGAS(W,P,T, IGAS)	ISENTROPIC speed of sound of the gas igas	m/s	4/21

## Units:

Symbol	Name	Unit
t	Temperature	°C
p	Mixture pressure	bar
igas	Number of the gas	

## Reference states:

Property	Gases (except steam)	Steam
Pressure	1.01325 bar	0.006112127 bar
Temperature	0 °C	0 °C
Enthalpy	0 kJ/kg	2500.9342 kJ/kg
Entropy	0 kJ/(kg K)	9.15591 kJ/(kg K)

## Types of variables for the function call from the LibIdGasMix DLL:

All functions	Real*8
Variable p, t, v, h, s	Real*8
Variable igas	Integer*4

## 1.4 Range of Validity

Table 1 contains a list of gases which can be calculated in the LibIdGasMix property library either as a component of a gas mixture or as a single gas. The calculation of thermodynamic properties is carried out by the algorithms stated in Table 1. The algorithms for the transport properties are listed in Table 2.

The calculation programs are valid in a temperature range

from  $t = -73.15 \text{ } ^\circ\text{C}$  to  $3026.85 \text{ } ^\circ\text{C}$ .

Exceptions are:

Fluorine from  $-73.15 \text{ } ^\circ\text{C}$  to  $976.85 \text{ } ^\circ\text{C}$ .

The pressure range is limited to the region where the mixture gases or single gases can be considered as ideal gases and, thus, ranges

from above 0.01 bar to 10 (30) bar, maximum 50 bar.

For temperatures above  $1000 \text{ } ^\circ\text{C}$  and mole fractions of oxygen of more than 10 % ( $\psi_{\text{O}_2} \geq 0.1$ ) the dissociation based on the VDI 4670 for the gases nitrogen, oxygen, carbon dioxide, steam, and sulfur dioxide are considered. The dissociation of other gases is not considered. For programming reasons, the calculation of the correction for the dissociation is already carried out from  $500 \text{ } ^\circ\text{C}$ .

**Note:**

A calculated value of -9999 indicates that the input values have been entered outside the range of validity and/or the sum of the values  $\xi_1, \dots, \xi_{30}$  or  $\psi_1, \dots, \psi_{30}$  entered does not result in 1.

## Additional Information

For further information, please see Table 3 which provides data of critical points (c) and triple states (t) of the gas  $i$  which is determined as follows:

$$t_{t,i} > t_{\min}$$

and/or

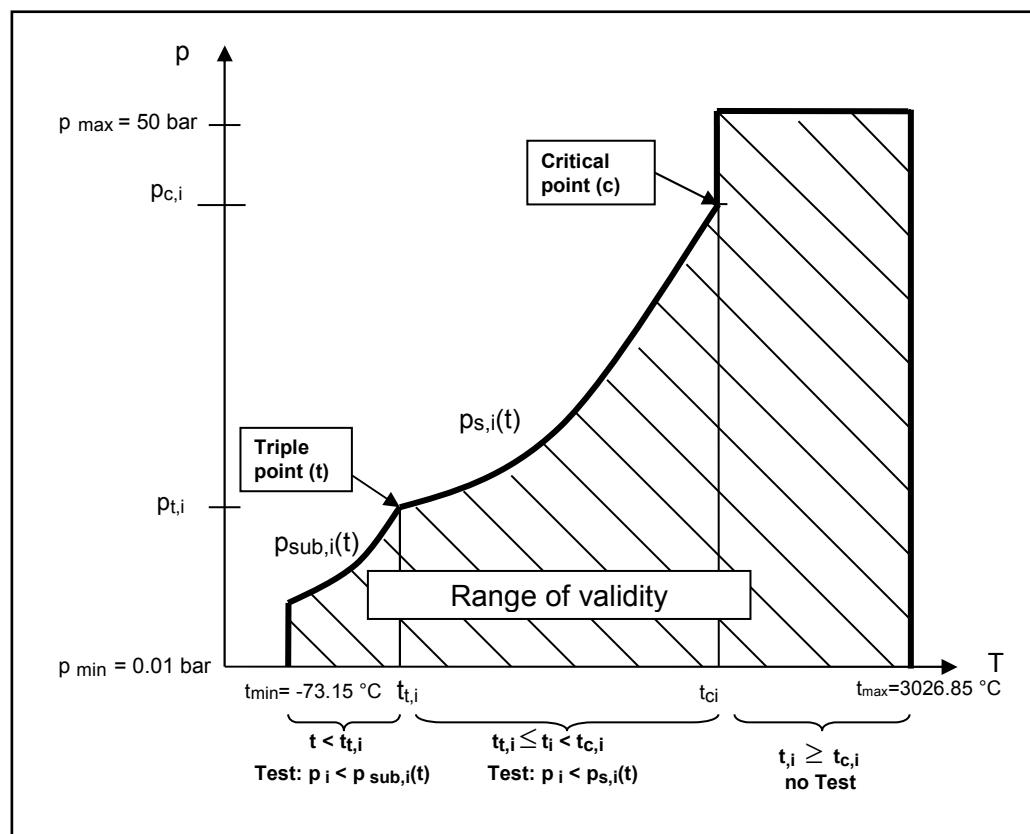
$$t_{c,i} > t_{\min}.$$

This means the triple state and/or the critical point of the gas  $i$  is located in the LibIdGasMix range of validity. In the LibIdGasMix program, corresponding to Figure 1, for every gas  $i = i_{\text{gas}}$  is examined whether it is actually existent in the gaseous state at the given temperature  $t$  and its present partial pressure  $p_i$ .

If the given temperature  $t$  is lower than the triple temperature  $t_{t,i}$  of the gas  $i$ ,  $p_i \leq p_{\text{sub},i}(t)$  has to be fulfilled with  $p_{\text{sub},i}(t)$  as the sublimation pressure of the gas number  $i$ ; see Figure 1. If not, the result is - xx999, for which xx is the number of the gas corresponding to Table 1. This test is carried out for H<sub>2</sub>O and CO<sub>2</sub>.

If the given temperature  $t$  has a value between the triple temperature and the critical temperature the relation  $p_i \leq p_{s,i}(t)$  has to be valid for the partial pressure  $p_i$ , where  $p_{s,i}(t)$  is the saturation pressure of the gas  $i$ ; see Figure 1. If not, the result will again be - xx999. The gases to be tested are listed in Table 3. This table also contains values of the critical and tripel states.

The calculation is carried out in any case at temperatures above the critical temperature.



**Figure 1.** p-t diagram with the range of validity of a gas  $i = i_{\text{gas}}$  of the LibIdGasMix property library.

**Table 3.** Data of triple states (t) and critical points (c).

Gas No. i	Mixture gas		Critical point		ps(t)	Triple state		p <sub>sub(t)</sub> [Source]
			p <sub>c i</sub> in bar[Source]	t <sub>c i</sub> in °C[Source]		p <sub>t i</sub> in bar[Source]	t <sub>t i</sub> in °C [Source]	
1	Ar	Argon						
2	Ne	Neon						
3	N <sub>2</sub>	Nitrogen						
4	O <sub>2</sub>	Oxygen						
5	CO	Carbon monoxide						
6	CO <sub>2</sub>	Carbon dioxide	73.773 [36]	30.9782 [36]	[36]	5.1795 [36]	- 56.558 [36]	[36]
7	H <sub>2</sub> O	Steam	220.69 [39]	373.946 [39]	[39]	0.00611657 [39]	0.01 [39]	[39]
8	SO <sub>2</sub>	Sulfur dioxide	78.8 [20]	157.45 [20]	[20]			
9	AIR	Air (dry)						
10	AIR-N <sub>2</sub>	Air nitrogen						
11	NO	Nitrogen oxide						
12	H <sub>2</sub> S	Sulfur hydrogen		99.95 [41]	[41]			
13	OH	Hydroxyl						
14	CH <sub>3</sub> OH	Methanol	81.035 [26]	239.45 [26]	[26]			
15	CH <sub>4</sub>	Methane						
16	C <sub>2</sub> H <sub>4</sub>	Ethylene	50.418 [35]	9.2 [35]	[35]			
17	C <sub>2</sub> H <sub>6</sub>	Ethane	48.722 [26]	32.172 [26]	[29]			
18	C <sub>3</sub> H <sub>6</sub>	Propylene	46.646 [42]	92.42 [42]	[42]			
19	C <sub>3</sub> H <sub>8</sub>	Propane	42.4766 [43]	96.675 [43]	[43]			
20	n-C <sub>4</sub> H <sub>10</sub>	n-Butane	37.96 [26]	151.975 [26]	[26]			
21	Iso-C <sub>4</sub> H <sub>10</sub>	Iso-Butane	36.29 [26]	134.66 [26]	[26]			
22	C <sub>6</sub> H <sub>6</sub>	Benzene	48.9794 [44]	289.01 [44]	[44]			
23	H <sub>2</sub>	Hydrogen						
24	He	Helium						
25	NH <sub>3</sub>	Ammonia	113.3926 [38],[40]	132.36 [38],[40]	[38],[40]			
26 to 29	free		-	-		-	-	
30	F <sub>2</sub>	Fluorine <sup>2)</sup>						

## 2 Application of FluidVIEW in LabVIEW™

The FluidVIEW Add-on has been developed to calculate thermodynamic properties in LabVIEW™ (version 10.0 or higher) more conveniently. Within LabVIEW™, it enables the direct call of functions relating to ideal gas mixtures from the LibIdGasMix property library.

### 2.1 Installing FluidVIEW

If a FluidVIEW property library has not yet been installed, please complete the initial installation procedure described below.

If a FluidVIEW property library has already been installed, you only need to copy several files which belong to the LibIdGasMix library. In this case, follow the subsection "Adding the LibIdGasMix Library" on page 2/3.

In both cases folders and files from the zip archive

CD_FluidVIEW_LibIdGasMix.zip	(for 32-bit version of Windows®)
CD_FluidVIEW_LibIdGasMix_x64.zip	(for 64-bit version of Windows®)

have to be copied into the default directory of the LabVIEW™ development environment. In the following text these zipped directories for the 32-bit or 64-bit operating system will be symbolised with the term <CD>.

You can see the current default directory of LabVIEW™ in the paths page (options dialog box). To display this page please select *Tools* and click on *Options* to open the options dialog box and then select *Paths* from the category list.

By choosing *Default Directory* from the drop-down list the absolute pathname to the default directory, where LabVIEW™ automatically stores information, is displayed. In the following sections the pathname of the default directory will be symbolised by the term <LV>.

### Additional Requirement When Using a 64-bit Operating System

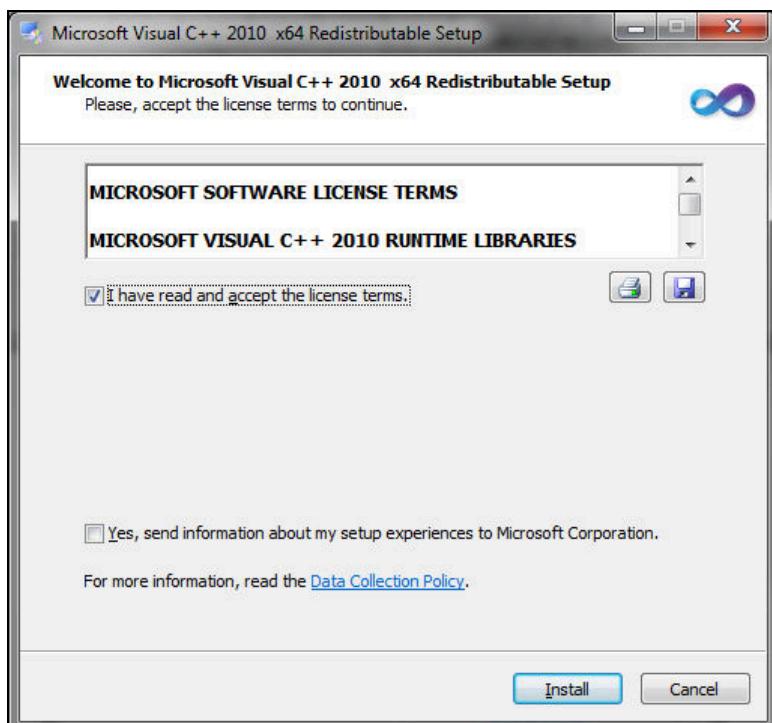
If you want to use FluidVIEW on a 64-bit computer that does not have Visual C++ installed, please make sure the Microsoft Visual C++ 2010 x64 Redistributable Package is installed.

If it is not the case, please install it by double clicking the file

`vcredist_x64.exe`

which you find in the folder `\vcredist_x64` in the **64-bit** CD folder "`CD_FluidVIEW_LibIdGasMix_x64`".

In the following window you are required to accept the Microsoft® license terms to install the Microsoft Visual C++ 2010 runtime libraries by ticking the box next to "I have read and accept the license terms" (see Figure 2.1).



**Figure 2.1** Accepting the license terms to install the Microsoft Visual C++ 2010 x64 Redistributable Package

Now click on "Install" to continue installation.

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

Now you can use the FluidVIEW Add-On on your 64-bit operating system. Please follow the instructions below to install FluidVIEW.

### Initial Installation of FluidVIEW

The initial installation of FluidVIEW is carried out by copying three directories with its contents from the zip archive to the standard directory of LabVIEW™. The directories that have to be copied, their paths in the zip archive and their target paths are listed in Table 2.1.

The installation is complete after copying the files and restarting LabVIEW™.

Due to the fact, that the functions of the DLL are called with a variable pathname, the source files you will find in the directory <CD>\source can be stored in a random directory. The pathname has to be indicated in order to calculate the property functions.

All source files have to be stored in the same directory to make the property functions of the LibIdGasMix library work. These files are for the

- **32-bit system:** LibIdGasMix.dll, advapi32.dll, Dformd.dll, Dforrt.dll, LC.dll, msdp60.dll, and msrvct.dll

and for the

- **64-bit system:** LibIdGasMix.dll, capt\_ico\_big.ico, LC.dll, libifcoremd.dll, libomp5md.dll, and libmmd.dll.

**Table 2.1** Directories which have to be copied from the zip archive in the default directory of LabVIEW™ (<LV>) for the initial installation of FluidVIEW

Name of the directory	Pathname in the zip archive	Target path in the default directory of LabVIEW (<LV>)
FluidVIEW	<CD>\vi.lib	<LV>\vi.lib
FluidVIEW	<CD>\menus\Categories	<LV>\menus\Categories
FluidVIEW-Help	<CD>\help	<LV>\help

### Adding the LibIdGasMix Library

In order to add the LibIdGasMix property library to an existing FluidVIEW installation, one folder with its contents and five files have to be copied from the zip archive to the standard directory of LabVIEW™. This directory, the files plus their pathnames in the zip archive and their target paths are listed in Table 2.2.

The installation is complete after copying the files and restarting LabVIEW™. Due to the fact, that the functions of the DLL are called with a variable pathname, the source files you will find in the directory <CD>\source can be stored in a random directory. The pathname has to be indicated in order to calculate the property functions. All source files have to be stored in the same directory to make the property functions of the LibIdGasMix library work. These files are for the

- **32-bit system:** LibIdGasMix.dll, advapi32.dll, Dformd.dll, Dforrt.dll, LC.dll, msdp60.dll, and msvcrt.dll
- and for the
- **64-bit system:** LibIdGasMix.dll, capt\_ico\_big.ico, LC.dll, libifcoremd.dll, libomp5md.dll, and libmmd.dll

**Table 2.2** Data which have to be copied from the zip archive in the default directory of LabVIEW™ (<LV>) for adding the LibIdGasMix property library to an existing installation of FluidVIEW

File name with file extension or name of the directory	Pathname in the zip archive	Target path in the default directory of LabVIEW (<LV>)
LibIdGasMix.llb	<CD>\vi.lib\FluidVIEW	<LV>\vi.lib\FluidVIEW
LibIdGasMix	<CD>\menus\Categories\FluidVIEW	<LV>\menus\Categories\FluidVIEW
LibIdGasMix.hlp	<CD>\help\FluidVIEW-Help	<LV>\help\FluidVIEW-Help
LibIdGasMix.txt	<CD>\help\FluidVIEW-Help	<LV>\help\FluidVIEW-Help
FluidVIEW_LibIdGasMix.pdf	<CD>\help\FluidVIEW-Help	<LV>\help\FluidVIEW-Help
Open_LibIdGasMix_doc.vi	<CD>\help\FluidVIEW-Help	<LV>\help\FluidVIEW-Help
Open_LibIdGasMix_doc.txt	<CD>\help\FluidVIEW-Help	<LV>\help\FluidVIEW-Help

After you have restarted LabVIEW™ you will find the functions of the LibIdGasMix property library in the functions palette under the sub palette FluidVIEW. An example calculation of the specific enthalpy  $h$  and the specific entropy  $s$  is shown in section 2.4.

## 2.2 The FluidVIEW Help System

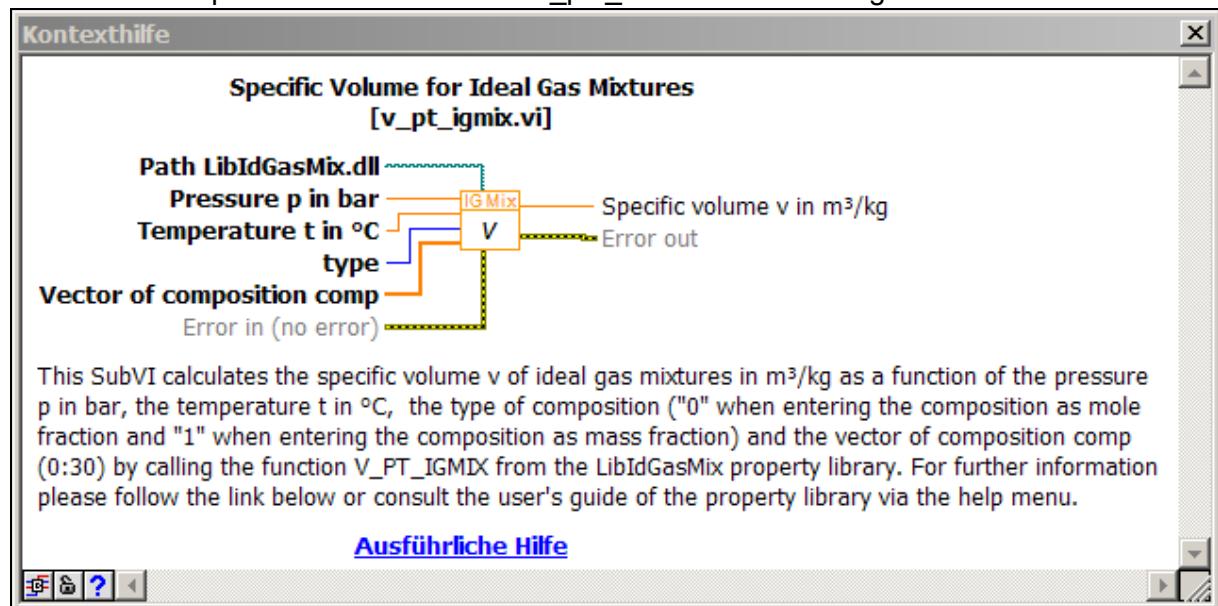
FluidVIEW provides detailed online help functions.

### General Information

The FluidVIEW Help System consists of the Microsoft WinHelp file **LibIdGasMix.chm** and this user's guide as PDF document **FluidVIEW\_LibIdGasMix.pdf**. Both files can be opened via the help menu. To do this please click **Help** in the menu bar. In the submenu *FluidVIEW-Help* you will find the commands *LibIdGasMix Help File* and *LibIdGasMix User's Guide* to open an appropriate file.

### Context-Sensitive Help

If you have activated the context help function in LabVIEW™ (Ctrl-H) and move the cursor over a FluidVIEW object basic information is displayed in the context help window. The in- and output parameters plus a short information text are displayed for a property function. By clicking the **Detailed help** button in the **Context help** window the online help will be opened. The context help window of the function *v\_ptx\_air.vi* is shown in Figure 2.2.



**Figure 2.2** Context help window of the function *v\_ptx\_air.vi*

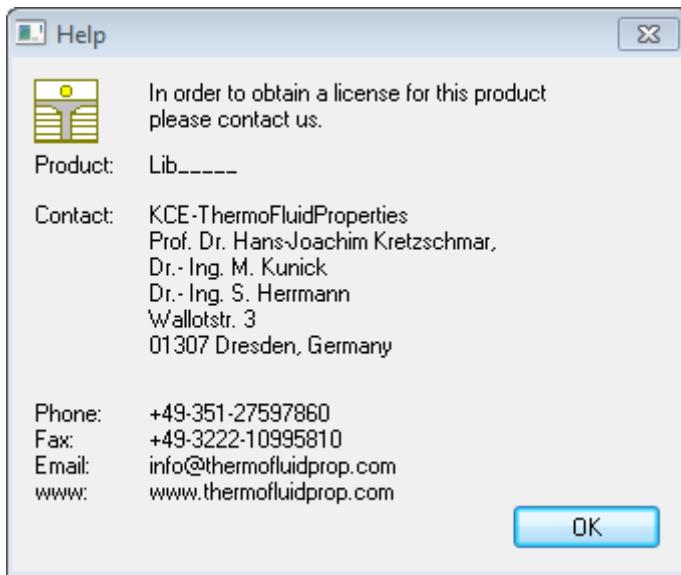
## 2.3 Licensing the LibIdGasMix Property Library

The licensing procedure has to be carried out when calculating a LibIdGasMix function and a FluidVIEW prompt message appears. In this case, you will see the "License Information" window (see figure below).



**Figure 2.3** "License Information" window

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



**Figure 2.4** "Help" window

If you do not enter a valid license it is still possible to run your VI by clicking "Cancel". In this case, the LibIdGasMix property library will display the result "-1.11111E+7" for every calculation.

The "License Information" window will appear every time you reopen your Virtual Instrument (VI) or reload the path of the LibIdGasMix.dll. Should you not wish to license the LibIdGasMix property library, you have to uninstall FluidVIEW according to the description in section 2.6 of this User's Guide.

**Note:**

*The product name "Lib\_\_\_\_\_ in the Figures above stands for the Library you are installing.*

## 2.4 Example: Calculation of $h = f(p, t, \xi_1 \dots \xi_{30})$ of the Gas Mixture

After the delivered files have been copied in the appropriate folders of the default directory LabVIEW™ (described in section 2.1), the LibIdGasMix property library is ready to use. The function nodes of the LibIdGasMix property library can be used by dragging them from the functions palette into the block diagram and connecting them with the wires representing the required input parameters.

Now we will calculate, step by step, the specific enthalpy  $h$  as a function of pressure of  $p = 1.45$  bar and a temperature of  $t = 100$  °C for a given mixture composed of the following mass fractions using FluidVIEW.

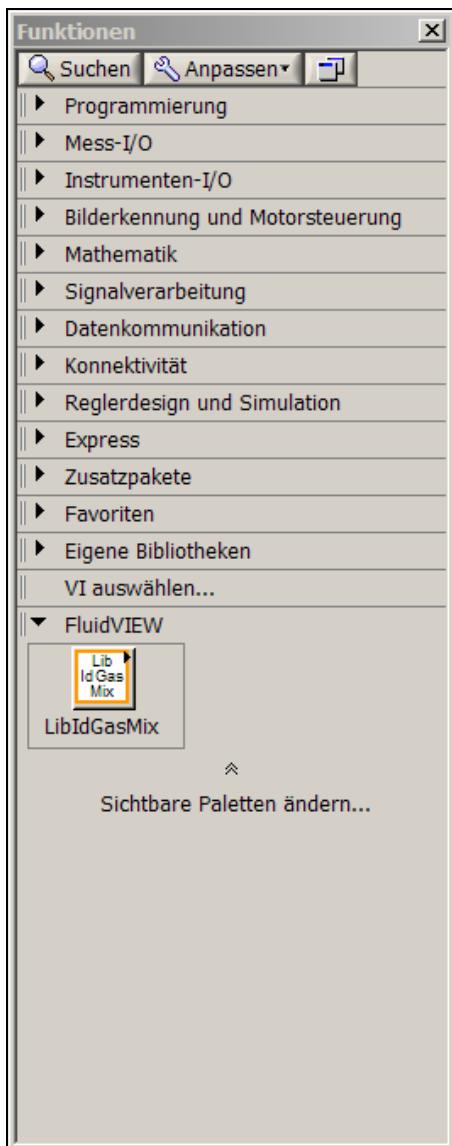
Mass fraction in %	Mixture gas
12	Neon
9	Steam
21	Air
39	Ethylene
14	n-Butane
5	Hydrogen

Corresponding to table 1 in chapter 1.1 the given mixture gases take the following numbers in the LibIdGasMix library. The given mass fractions have been added:

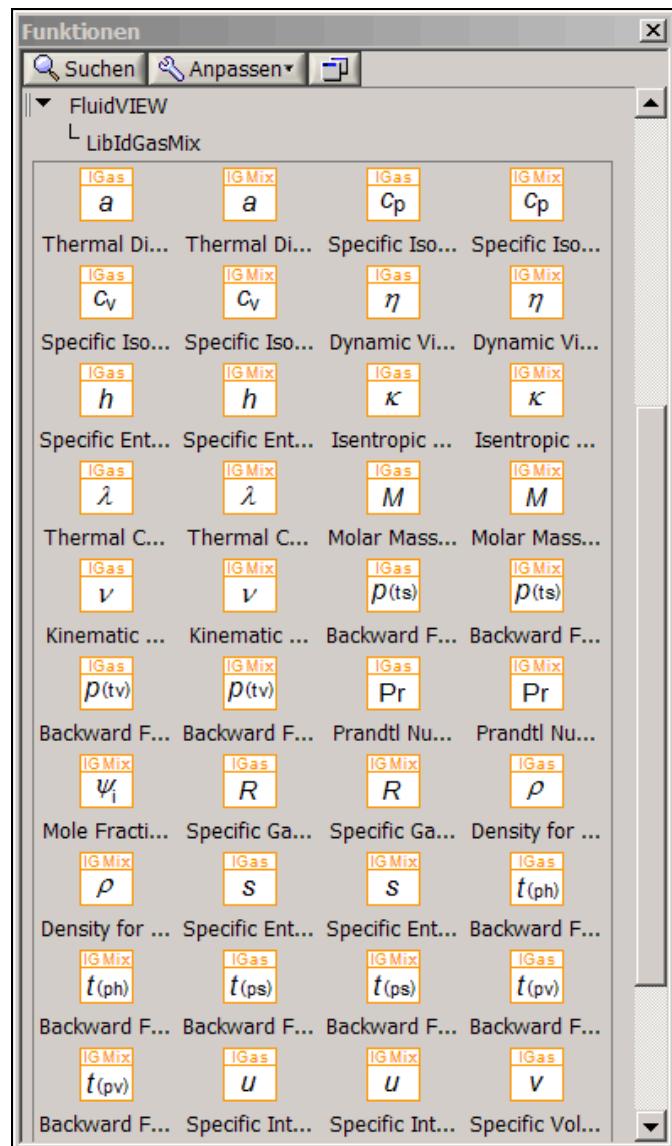
Gas no. i	Mixture gas	$\xi_i$ in kg/kg
2	Neon	0.12
7	Steam	0.09
9	Air	0.21
16	Ethylene	0.39
20	n-Butane	0.14
23	Hydrogen	0.05

You have to carry out the following steps to calculate the specific enthalpy  $h$ :

- Start LabVIEW™ and wait for the *Getting Started* window to be displayed. Then select *Blank VI*. The *Blank VI* will be displayed in two windows, the front panel and the block diagram.
- Open the functions palette in the block diagram **via view / Functions Palette** (or by clicking the right mouse button anywhere in the free area of the block diagram) if not yet displayed.
- In addition to the default LabVIEW™ palettes the functions palette contains the sub palette *FluidVIEW* (see Figure 2.5) with the sub palette *LibIdGasMix* (see Figure 2.6).

**Figure 2.5**

Functions palette with the sub palettes FluidVIEW and LibHuGas

**Figure 2.6**

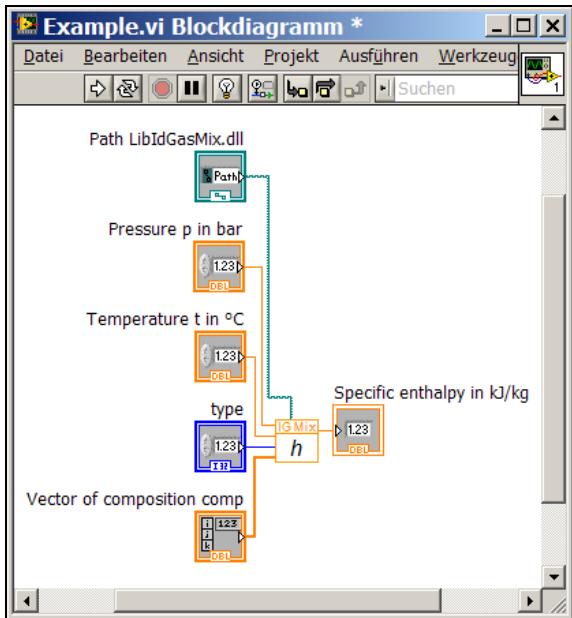
Functions palette with the property functions of the LibHuGas library

In order to calculate the specific enthalpy  $h$ , drag the function (SubVI) whose symbol shows the  $h$  from the functions palette into the block diagram.

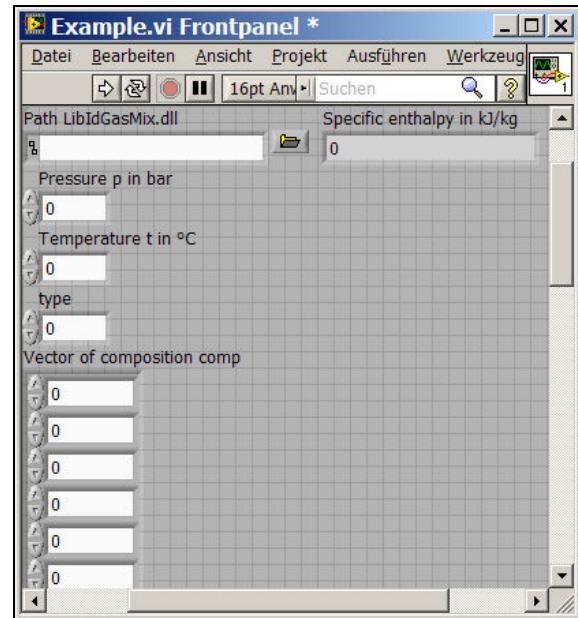
While the short names of the SubVIs behind the symbols will be shown in the control tip, the full names and brief descriptions of the property functions are displayed in the *Context Help* window (see Figure 2.2). To use the context help press  $<\text{Ctrl}>+<\text{H}>$  on your keyboard.

- After placing the node of the SubVI **h\_pt\_igmix.vi** on your block diagram the required input parameters have to be defined. The input parameters which are set as required appear in bold type in the Context Help window. In this case these input parameters are **Path LibIdGasMix.dll** (LabVIEW™ data type: Path), **Pressure p in bar** (LabVIEW™ data type: Double precision, floating-point), **Temperature t in °C** (LabVIEW™ data type: Double precision, floating-point) **type** (LabVIEW™ data type: Long signed integer) and **Vector of composition comp** (1-D Array, LabVIEW™ data type: Double precision, floating-point).

- To define these variables wire their input terminals with input elements on the front panel. You can accomplish this in one step by choosing **Create / Control** in the context menu of all required input terminals. In order to wire the output terminal of the function node with an output element on the front panel, choose **Create / Indicator** in the context menu of the output terminal **Specific enthalpy h in kJ/kg** (LabVIEW™ data type: Double precision, floating-point). After cleaning up the block diagram by pressing <Ctrl>+<U> it has the appearance illustrated in Figure 2.7. The same input and output elements are available on the appropriate front panel (see Figure 2.8).



**Figure 2.7**  
Block diagram of the example calculation



**Figure 2.8**  
Front panel of the example calculation

- Enter the path of the LibIdGasMix.dll in the input element *Path LibIdGasMix.dll* on the front panel (as explained in section 2.1 the LibIdGasMix.dll and the other library files from the directory <CD>\source have to be stored in the same directory which is arbitrary). To do this you can use the *File Open Dialog* which appears by clicking the yellow folder symbol on the right of the input element.
- Enter a value in the input element *pressure p in bar* on the front panel (Range of validity:  $p = 0.01 \text{ mbar}$  up to 50 bar)  
 ⇒ e. g.: Enter the value 1.45
- Enter a value in the input element *temperature t in °C* on the front panel (Range of validity:  $t = -73.15 \text{ °C} \dots 3026.85 \text{ °C}$ )  
 ⇒ e. g.: Enter the value 100
- Enter a specification into the input element *type* on the front panel. This input determines whether the entry of the composition vector *comp* will be made in mass fractions or mole fractions, i.e., volume fractions.  
 Type = 1 for the entry of mass fractions  $\xi_1 \dots \xi_{30}$   
 Type = 0 for the entry of mole fractions, i.e., volume fractions  $\gamma_1 \dots \gamma_{30}$   
 ⇒ e. g.: Enter the value 1

- Enter the given mass fractions  $\xi_1 \dots \xi_{30}$  of the mixture gases into the input element *Vector of composition comp* on the frontpanel. In doing so, please consider, that the vector *comp* consists of the elements 0 to 30. Whereas the element 0 is a dummy.

$\xi_1$	for argon	Ar	<a href="#">⇒ e.g.: Enter 0</a>	into element 01
$\xi_2$	for neon	Ne	<a href="#">⇒ e.g.: Enter 0.12</a>	into element 02
$\xi_3$	for nitrogen	N <sub>2</sub>	<a href="#">⇒ e.g.: Enter 0</a>	into element 03
$\xi_4$	for oxygen	O <sub>2</sub>	<a href="#">⇒ e.g.: Enter 0</a>	into element 04
$\xi_5$	for carbon monoxide	CO	<a href="#">⇒ e.g.: Enter 0</a>	into element 05
$\xi_6$	for carbon dioxide	CO <sub>2</sub>	<a href="#">⇒ e.g.: Enter 0</a>	into element 06
$\xi_7$	for steam	H <sub>2</sub> O	<a href="#">⇒ e.g.: Enter 0.09</a>	into element 07
$\xi_8$	for sulfur dioxide	SO <sub>2</sub>	<a href="#">⇒ e.g.: Enter 0</a>	into element 08
$\xi_9$	for air - dry		<a href="#">⇒ e.g.: Enter 0.21</a>	into element 09
$\xi_{10}$	for atmospheric nitrogen		<a href="#">⇒ e.g.: Enter 0</a>	into element 10
$\xi_{11}$	for nitrogen oxide	NO	<a href="#">⇒ e.g.: Enter 0</a>	into element 11
$\xi_{12}$	for hydrogen sulfide	H <sub>2</sub> S	<a href="#">⇒ e.g.: Enter 0</a>	into element 12
$\xi_{13}$	for hydroxyl	OH	<a href="#">⇒ e.g.: Enter 0</a>	into element 13
$\xi_{14}$	for methanol	CH <sub>3</sub> OH	<a href="#">⇒ e.g.: Enter 0</a>	into element 14
$\xi_{15}$	for methane	CH <sub>4</sub>	<a href="#">⇒ e.g.: Enter 0</a>	into element 15
$\xi_{16}$	for ethylene	C <sub>2</sub> H <sub>4</sub>	<a href="#">⇒ e.g.: Enter 0.39</a>	into element 16
$\xi_{17}$	for ethane	C <sub>2</sub> H <sub>6</sub>	<a href="#">⇒ e.g.: Enter 0</a>	into element 17
$\xi_{18}$	for propylene	C <sub>3</sub> H <sub>6</sub>	<a href="#">⇒ e.g.: Enter 0</a>	into element 18
$\xi_{19}$	for propane	C <sub>3</sub> H <sub>8</sub>	<a href="#">⇒ e.g.: Enter 0</a>	into element 19
$\xi_{20}$	for n-butane	C <sub>4</sub> H <sub>10</sub>	<a href="#">⇒ e.g.: Enter 0.14</a>	into element 20
$\xi_{21}$	for iso-butane	C <sub>4</sub> H <sub>10</sub>	<a href="#">⇒ e.g.: Enter 0</a>	into element 21
$\xi_{22}$	for benzene	C <sub>6</sub> H <sub>6</sub>	<a href="#">⇒ e.g.: Enter 0</a>	into element 22
$\xi_{23}$	for hydrogen	H <sub>2</sub>	<a href="#">⇒ e.g.: Enter 0.05</a>	into element 23
$\xi_{24}$	for helium	He	<a href="#">⇒ e.g.: Enter 0</a>	into element 24
$\xi_{25}$	for ammonia	NH <sub>3</sub>	<a href="#">⇒ e.g.: Enter 0</a>	into element 25
$\xi_{26}$	free		<a href="#">⇒ e.g.: Enter 0</a>	into element 26
$\xi_{27}$	free		<a href="#">⇒ e.g.: Enter 0</a>	into element 27
$\xi_{28}$	free		<a href="#">⇒ e.g.: Enter 0</a>	into element 28
$\xi_{29}$	free		<a href="#">⇒ e.g.: Enter 0</a>	into element 29
$\xi_{30}$	for fluorine	F <sub>2</sub>	<a href="#">⇒ e.g.: Enter 0</a>	into element 30

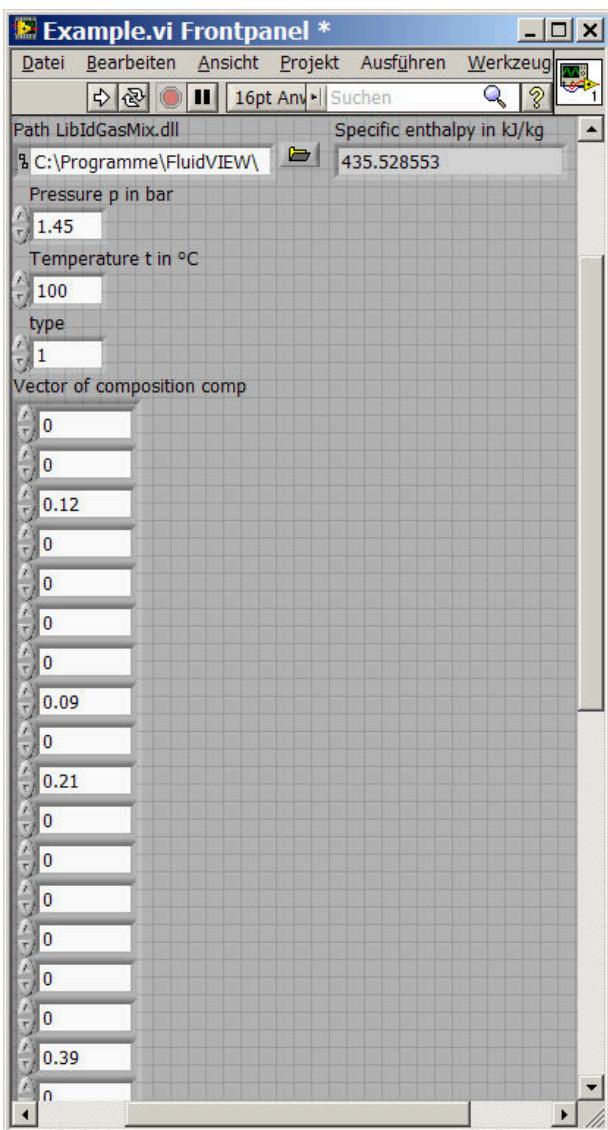
### Note!

The gas numbers 26 to 29 are currently not defined. All entries above 0 (zero) made into these cells result in – xx0999, for which xx corresponds to the gas number. Please note that due to its chemical properties, fluorine can be calculated only as a mixture gas with  $\xi_{30} = 1$  or  $\psi_{30} = 1$ . If it is entered as a mixture gas with  $\xi_{30} < 1$  or  $\psi_{30} < 1$  the value calculated will result in 30999.

- To run the calculation of the specific enthalpy click on the *Run* button or press <Ctrl>+<R>. The result for  $h$  in kJ/kg appears in the output element (see Figure 2.9).
 

⇒ The result for  $h$  in our sample calculation is  $h = 435.528553$  kJ/kg.

The calculation of  $h = f(p, t, \xi_1 \dots \xi_{30})$  has thus been completed.



**Figure 2.9** Result of the example calculation of  $h$

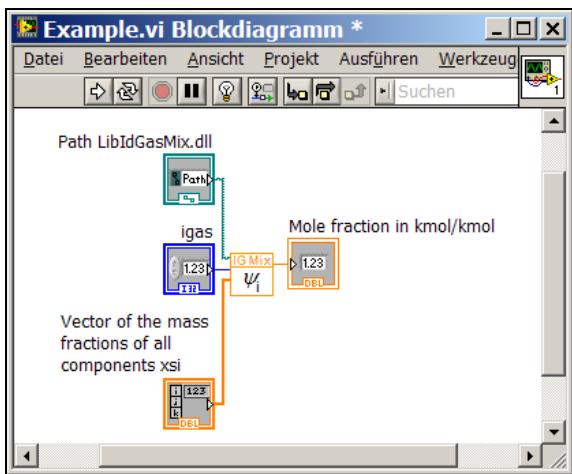
### Important!

LibIdGasMix checks internally whether the partial pressures of the mixture gases comprising the composition and the total pressure are lower than the saturation pressure at a given temperature. If this not be the case, the calculation will result in "-xx999", for which xx corresponds to the gas number, e.g., -7999 for steam.

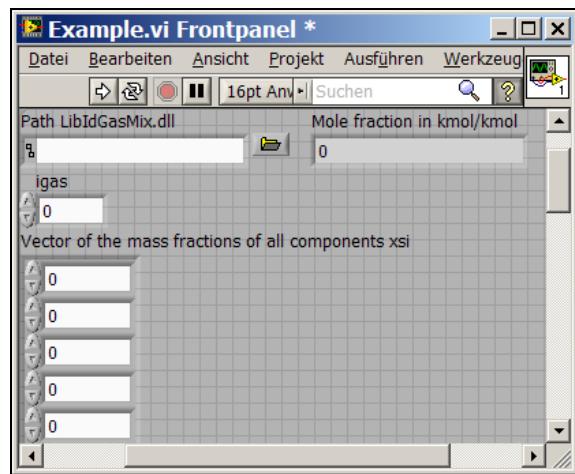
## 2.5 Example: Calculation of the Mole Fraction $\psi_i = f(i_{\text{gas}}, \xi_1 \dots \xi_{30})$ of the Gas i within the Gas Mixture

After calculating a property function depending on pressure  $p$ , temperature  $t$  and the mass fraction of the mixture components (described in part 2.4), now we will compute the mole fraction of ethylene ( $C_2H_4$ ). In addition to the mass fractions of the mixture components only the gas number  $i_{\text{gas}}$  has to be specified. Carry out the following steps:

- Open the functions palette in the block diagram via **view / Functions Palette** (or by clicking the right mouse button anywhere in the free area of the block diagram) if not yet displayed.
- In addition to the default LabVIEW™ palettes the functions palette contains the sub palette *FluidVIEW* (see Figure 2.8) with the sub palette *LibIdGasMix* (see Figure 2.9). In order to calculate the mole fraction  $\psi_i$ , drag the *igmix* function (SubVI) whose symbol shows the  $\psi$  from the functions palette into the block diagram. While the short names of the SubVIs behind the symbols will be shown in the control tip (in this case “Mole Fraction of the Gas  $i_{\text{gas}}$  for Ideal Gas Mixtures”), the full names and brief descriptions of the property functions are displayed in the *Context Help* window (see Figure 2.2). To use the context help press  $<\text{Ctrl}>+<\text{H}>$  on your keyboard.
- After placing the node of the SubVI **psi\_igas\_xsi\_igmix.vi** on your block diagram the required input parameters have to be defined. The input parameters which are set as required appear in bold type in the Context Help window. In this case these input parameters are **Path LibIdGasMix.dll** (LabVIEW™ data type: Path), the gas number **igas** (LabVIEW™ data type: Long signed integer) and **Vector of the mass fractions of all components xsi** (1-D Array, LabVIEW™ data type: Double precision, floating-point).
- To define these variables wire their input terminals with input elements on the front panel. You can accomplish this in one step by choosing **Create / Control** in the context menu of all required input terminals. In order to wire the output terminal of the function node with an output element on the front panel, choose **Create / Indicator** in the context menu of the output terminal **Mole fraction psi** (LabVIEW™ data type: Double precision, floating-point). After cleaning up the block diagram by pressing  $<\text{Ctrl}>+<\text{U}>$  it has the appearance illustrated in Figure 2.13. The same input and output elements are available on the appropriate front panel (see Figure 2.14).



**Figure 2.10**  
Block diagram of the example calculation



**Figure 2.11**  
Front panel of the example calculation

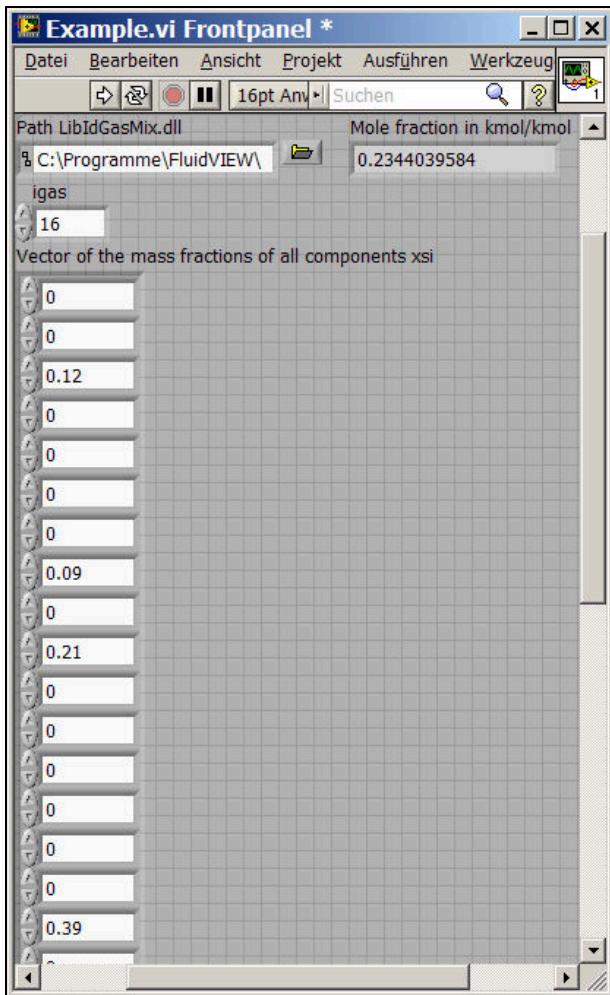
- Enter the path of the LibIdGasMix.dll in the input element *Path LibIdGasMix.dll* on the front panel (as explained in section 2.1 the LibIdGasMix.dll and the other library files from the directory **<CD>\source** have to be stored in the same directory which is arbitrary). To do this you can use the *File Open Dialog* which appears by clicking the yellow folder symbol on the right of the input element.
- Enter the gas number for ethylene in the input element *igas* on the front panel  
⇒ e. g.: Enter the gas number 16
- Enter the given mass fractions  $\xi_1 \dots \xi_{30}$  of the mixture gases into the input element *Vector of composition comp* on the frontpanel. In doing so, please consider, that the vector *comp* consists of the elements 0 to 30. Whereas the element 0 is a dummy.

$\xi_1$	for argon	Ar	⇒ e.g.: Enter 0	into element 01
$\xi_2$	for neon	Ne	⇒ e.g.: Enter 0.12	into element 02
$\xi_3$	for nitrogen	N <sub>2</sub>	⇒ e.g.: Enter 0	into element 03
$\xi_4$	for oxygen	O <sub>2</sub>	⇒ e.g.: Enter 0	into element 04
$\xi_5$	for carbon monoxide	CO	⇒ e.g.: Enter 0	into element 05
$\xi_6$	for carbon dioxide	CO <sub>2</sub>	⇒ e.g.: Enter 0	into element 06
$\xi_7$	for steam	H <sub>2</sub> O	⇒ e.g.: Enter 0.09	into element 07
$\xi_8$	for sulfur dioxide	SO <sub>2</sub>	⇒ e.g.: Enter 0	into element 08
$\xi_9$	for air - dry		⇒ e.g.: Enter 0.21	into element 09
$\xi_{10}$	for atmospheric nitrogen		⇒ e.g.: Enter 0	into element 10
$\xi_{11}$	for nitrogen oxide	NO	⇒ e.g.: Enter 0	into element 11
$\xi_{12}$	for hydrogen sulfide	H <sub>2</sub> S	⇒ e.g.: Enter 0	into element 12
$\xi_{13}$	for hydroxyl	OH	⇒ e.g.: Enter 0	into element 13
$\xi_{14}$	for methanol	CH <sub>3</sub> OH	⇒ e.g.: Enter 0	into element 14
$\xi_{15}$	for methane	CH <sub>4</sub>	⇒ e.g.: Enter 0	into element 15
$\xi_{16}$	for ethylene	C <sub>2</sub> H <sub>4</sub>	⇒ e.g.: Enter 0.39	into element 16
$\xi_{17}$	for ethane	C <sub>2</sub> H <sub>6</sub>	⇒ e.g.: Enter 0	into element 17
$\xi_{18}$	for propylene	C <sub>3</sub> H <sub>6</sub>	⇒ e.g.: Enter 0	into element 18
$\xi_{19}$	for propane	C <sub>3</sub> H <sub>8</sub>	⇒ e.g.: Enter 0	into element 19
$\xi_{20}$	for n-butane	C <sub>4</sub> H <sub>10</sub>	⇒ e.g.: Enter 0.14	into element 20
$\xi_{21}$	for iso-butane	C <sub>4</sub> H <sub>10</sub>	⇒ e.g.: Enter 0	into element 21
$\xi_{22}$	for benzene	C <sub>6</sub> H <sub>6</sub>	⇒ e.g.: Enter 0	into element 22
$\xi_{23}$	for hydrogen	H <sub>2</sub>	⇒ e.g.: Enter 0.05	into element 23
$\xi_{24}$	for helium	He	⇒ e.g.: Enter 0	into element 24
$\xi_{25}$	for ammonia	NH <sub>3</sub>	⇒ e.g.: Enter 0	into element 25
$\xi_{26}$	free		⇒ e.g.: Enter 0	into element 26
$\xi_{27}$	free		⇒ e.g.: Enter 0	into element 27
$\xi_{28}$	free		⇒ e.g.: Enter 0	into element 28
$\xi_{29}$	free		⇒ e.g.: Enter 0	into element 29
$\xi_{30}$	for fluorine	F <sub>2</sub>	⇒ e.g.: Enter 0	into element 30

- To run the calculation of the mole fraction click on the *Run* button or press  $<\text{Ctrl}>+<\text{R}>$ . The result for  $\psi$  in kmol/kmol appears in the output element (see Figure 2.9).

⇒ The result in our sample calculation here is: 0.2344039584 in kmol/kmol

The calculation of  $\psi = f(i_{\text{gas}}, \xi_1 \dots \xi_{30})$  has thus been completed.



**Figure 2.12** Result of the example calculation of  $\psi$

### Important!

LibIdGasMix checks internally whether the partial pressures of the mixture gases comprising the composition and the total pressure are lower than the saturation pressure at a given temperature. If this not be the case, the calculation will result in "-xx999", for which xx corresponds to the gas number, e.g., -7999 for steam.

## 2.6 Removing FluidVIEW

Should you wish to remove the LibIdGasMix library or the complete FluidVIEW Add-on you have to delete the files that have been copied in the default directory of the LabVIEW™ development environment <LV>.

### Removing the FluidVIEW Add-on

To remove the FluidVIEW Add-on please delete the folders listed in Table 2.3 from the default directory of LabVIEW™.

**Table 2.3** Directories that have to be deleted from the default directory of LabVIEW™ to remove the FluidVIEW Add-on

Name of the directory	Path in the default directory of LabVIEW™ (<LV>)
FluidVIEW	<LV>\vi.lib
FluidVIEW	<LV>\menus\Categories
FluidVIEW-Help	<LV>\help

### Removing only the LibIdGasMix library

To remove only the LibIdGasMix library please delete the folders or files listed in Table 2.4 from the default directory of LabVIEW™.

**Table 2.4** Data that have to be deleted from the default directory of LabVIEW™ (<LV>) to remove only the LibIdGasMix library.

File name with file extension or name of the directory	Path in the default directory of LabVIEW (<LV>)
LibIdGasMix.llb	<LV>\vi.lib\FluidVIEW
LibIdGasMix	<LV>\menus\Categories\FluidVIEW
LibIdGasMix.hlp	<LV>\help\FluidVIEW-Help
LibIdGasMix.txt	<LV>\help\FluidVIEW-Help
FluidVIEW_LibIdGasMix.pdf	<LV>\help\FluidVIEW-Help
Open_LibIdGasMix_doc.vi	<LV>\help\FluidVIEW-Help
Open_LibIdGasMix_doc.txt	<LV>\help\FluidVIEW-Help

The changes will take effect after restarting LabVIEW™.

### 3. Software Documentation for Gas Mixtures (igmix-Functions)

**Thermal Diffusivity  $a = f(p, t, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$**

Function Name:	<b>a_pt_igmix</b>
Subprogram with function value:	<b>REAL*8 FUNCTION A_PT_IGMIX(P,T,TYPE, COMP)</b>
For call from FORTRAN:	REAL*8 P, T, COMP(0:30) INTEGER*4 TYPE
Subprogram with parameter:	<b>INTEGER*4 FUNCTION C_A_PT_IGMIX(A,P,T,TYPE, COMP)</b>
For call from DLL:	REAL*8 A, P, T, COMP(0:30) INTEGER*4 TYPE
<b>Input values:</b>	
P	- Total pressure $p$ in bar
T	- Temperature $t$ in °C
TYPE	- Type of composition: TYPE = 1 for the composition in mass fractions $\xi$ TYPE = 0 for the composition in mole fractions $\psi$
COMP(0:30)	- Composition in mass fractions $\xi_1 \dots \xi_{30}$ in kg / kg at TYPE = 1 - Composition in mole fractions $\psi_1 \dots \psi_{30}$ in kmol / kmol at TYPE = 0 COMP(0) - dummy COMP(1)...COMP(30) mass or mole fractions of the mixture gases (see table of <u>Combustion Gases</u> )

**Result:**

a\_pt\_igmix – Thermal diffusivity  $a$  in  $\text{m}^2 / \text{s}$

**Range of validity:**

Total pressure $p$ :	from 0.01 mbar to 50 bar
Temperature $t$ :	from -73.15 °C to 3026.85 °C
Exceptions:	Propylene from -73.15 °C to 1500 °C Fluorine from -73.15 °C to 976.8 °C

**Details:**

$$\text{Thermal diffusivity } a = \frac{\lambda}{\rho \cdot c_p}$$

**Results for wrong input values:**

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Specific Isobaric Heat Capacity $c_p = f(p, t, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name: **cp\_pt\_igmix**

Subprogram with function value: **REAL\*8 FUNCTION CP\_PT\_IGMIX(P,T,TYPE, COMP)**  
 For call from FORTRAN:  
**REAL\*8 P, T, COMP(0:30)**  
**INTEGER\*4 TYPE**

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_CP\_PT\_IGMIX(CP,P,T,TYPE, COMP)**  
 For call from DLL:  
**REAL\*8 CP, P, T, COMP(0:30)**  
**INTEGER\*4 TYPE**

### Input values:

P - Total pressure  $p$  in bar

T - Temperature  $t$  in °C

TYPE - Type of composition:  
 TYPE = 1 for the composition in mass fractions  $\xi$   
 TYPE = 0 for the composition in mole fractions  $\psi$

COMP(0:30) – Composition in mass fractions  $\xi_1 \dots \xi_{30}$  in kg / kg at TYPE = 1  
 – Composition in mole fractions  $\psi_1 \dots \psi_{30}$  in kmol / kmol at TYPE = 0  
 COMP(0) - dummy  
 COMP(1)...COMP(30) mass or mole fractions of the mixture gases  
 (see table of Combustion Gases)

### Result:

cp\_pt\_igmix – Specific isobaric heat capacity  $c_p$  in kJ / (kg K)

### Range of validity:

Total pressure  $p$  : from 0.01 mbar to 50 bar

Temperature  $t$  : from -73.15 °C to 3026.85 °C  
 Exceptions: Propylene from -73.15 °C to 1500 °C  
 Fluorine from -73.15 °C to 976.8 °C

### Details:

Model of the ideal mixture with in consideration of the dissociation effect  
 above 500 °C and  $\psi_{H_2O} \geq 0.1$

### Results for wrong input values:

Error	Meaning
-9999	input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Specific Isochoric Heat Capacity $c_v = f(p, t, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name:	<b>cv_pt_igmix</b>
Subprogram with function value:	<b>REAL*8 FUNCTION CV_PT_IGMIX(P,T,TYPE, COMP)</b>
For call from FORTRAN:	REAL*8 P, T, COMP(0:30) INTEGER*4 TYPE
Subprogram with parameter:	<b>INTEGER*4 FUNCTION C_CV_PT_IGMIX(CV,P,T,TYPE, COMP)</b>
For call from DLL:	REAL*8 CV, P, T, COMP(0:30) INTEGER*4 TYPE

### Input values:

P	- Total pressure $p$ in bar
T	- Temperature $t$ in °C
TYPE	- Type of composition: TYPE = 1 for the composition in mass fractions $\xi$ TYPE = 0 for the composition in mole fractions $\psi$
COMP(0:30)	- Composition in mass fractions $\xi_1 \dots \xi_{30}$ in kg / kg at TYPE = 1 - Composition in mole fractions $\psi_1 \dots \psi_{30}$ in kmol / kmol at TYPE = 0 COMP(0) - dummy COMP(1)...COMP(30) mass or mole fractions of the mixture gases (see table of <u>Combustion Gases</u> )

### Result:

cv\_pt\_igmix – Specific isochoric heat capacity  $c_v$  in kJ / (kg K)

### Range of validity:

Total pressure $p$ :	from 0.01 mbar to 50 bar
Temperature $t$ :	from -73.15 °C to 3026.85 °C
Exceptions:	Propylene from -73.15 °C to 1500 °C Fluorine from -73.15 °C to 976.8 °C

### Details:

$$c_v = c_p - R$$

### Results for wrong input values:

Error	Meaning
-9999	input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Dynamic Viscosity $\eta = f(p, t, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name:	<b>eta_pt_igmix</b>
Subprogram with function value:	<b>REAL*8 FUNCTION ETA_PT_IGMIX(P,T,TYPE, COMP)</b>
For call from FORTRAN:	REAL*8 P, T, COMP(0:30) INTEGER*4 TYPE
Subprogram with parameter:	<b>INTEGER*4 FUNCTION C_ETA_PT_IGMIX(ETA,P,T, TYPE, COMP)</b>
For call from DLL:	REAL*8 ETA, P, T, COMP(0:30) INTEGER*4 TYPE

**Input values:**

P	- Total pressure $p$ in bar
T	- Temperature $t$ in °C
TYPE	- Type of composition: TYPE = 1 for the composition in mass fractions $\xi$ TYPE = 0 for the composition in mole fractions $\psi$
COMP(0:30)	- Composition in mass fractions $\xi_1 \dots \xi_{30}$ in kg / kg at TYPE = 1 - Composition in mole fractions $\psi_1 \dots \psi_{30}$ in kmol / kmol at TYPE = 0 COMP(0) - dummy COMP(1)...COMP(30) mass or mole fractions of the mixture gases (see table of <u>Combustion Gases</u> )

**Result:**

eta\_pt\_igmix – Dynamic viscosity  $\eta$  in Pa s

**Range of validity:**

Total pressure $p$ :	from 0.01 mbar to 50 bar
Temperature $t$ :	from -73.15 °C to 3026.85 °C
Exceptions:	Propylene from -73.15 °C to 1500 °C Fluorine from -73.15 °C to 976.8 °C

**Details:**

Calculation according to *Brandt* [15] and *VB* [33] – model of the ideal mixture

**Results for wrong input values:**

Error	Meaning
-9999	input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Specific Enthalpy $h = f(p, t, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name: **h\_pt\_igmix**  
Subprogram with function value: **REAL\*8 FUNCTION H\_PT\_IGMIX(P,T,TYPE, COMP)**  
For call from FORTRAN:  
REAL\*8 P, T, COMP(0:30)  
INTEGER\*4 TYPE  
Subprogram with parameter:  
**INTEGER\*4 FUNCTION C\_H\_PT\_IGMIX(H,P,T,TYPE, COMP)**  
For call from DLL:  
REAL\*8 H, P, T, COMP(0:30)  
INTEGER\*4 TYPE

### Input values:

P - Total pressure  $p$  in bar  
T - Temperature  $t$  in °C  
TYPE - Type of composition:  
TYPE = 1 for the composition in mass fractions  $\xi$   
TYPE = 0 for the composition in mole fractions  $\psi$   
COMP(0:30) – Composition in mass fractions  $\xi_1 \dots \xi_{30}$  in kg / kg at TYPE = 1  
– Composition in mole fractions  $\psi_1 \dots \psi_{30}$  in kmol / kmol at TYPE = 0  
COMP(0) - dummy  
COMP(1)...COMP(30) mass or mole fractions of the mixture gases  
(see table of Combustion Gases)

### Result:

h\_pt\_igmix – Specific enthalpy  $h$  in kJ/kg

### Range of validity:

Total pressure  $p$  : from 0.01 mbar to 50 bar  
Temperature  $t$  : from -73.15 °C to 3026.85 °C  
Exceptions: Propylene from -73.15 °C to 1500 °C  
Fluorine from -73.15 °C to 976.8 °C

### Details:

Model of the ideal mixture in consideration of the dissociation effect

above 500 °C and  $\psi_{H_2O} \geq 0.1$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## ISENTROPIC EXPONENT $\kappa = f(p, t, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name: **kappa\_pt\_igmix**

Subprogram with function value: **REAL\*8 FUNCTION KAPPA\_PT\_IGMIX(P,T,TYPE, COMP)**  
 For call from FORTRAN:  
**REAL\*8 P, T, COMP(0:30)  
 INTEGER\*4 TYPE**

Subprogram with parameter: **INTEGER\*4 FUNCTION  
 C\_KAPPA\_PT\_IGMIX(KAPPA,P,T,TYPE, COMP)**  
 For call from DLL:  
**REAL\*8 KAPPA, P, T, COMP(0:30)  
 INTEGER\*4 TYPE**

### Input values:

P - Total pressure  $p$  in bar

T - Temperature  $t$  in °C

TYPE - Type of composition:  
 TYPE = 1 for the composition in mass fractions  $\xi$   
 TYPE = 0 for the composition in mole fractions  $\psi$

COMP(0:30) – Composition in mass fractions  $\xi_1 \dots \xi_{30}$  in kg / kg at TYPE = 1  
 – Composition in mole fractions  $\psi_1 \dots \psi_{30}$  in kmol / kmol at TYPE = 0  
 COMP(0) - dummy  
 COMP(1)...COMP(30) mass or mole fractions of the mixture gases  
 (see table of Combustion Gases)

### Result:

kappa\_pt\_igmix – Isentropic exponent  $\kappa$

### Range of validity:

Total pressure  $p$  : from 0.01 mbar to 50 bar

Temperature  $t$  : from -73.15 °C to 3026.85 °C  
 Exceptions: Propylene from -73.15 °C to 1500 °C  
 Fluorine from -73.15 °C to 976.8 °C

### Details:

$$\text{Kappa } \kappa = \frac{c_p}{c_p - R}$$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas no in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Thermal Conductivity $\lambda = f(p, t, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name: **lambda\_pt\_igmix**

Subprogram with function value: **REAL\*8 FUNCTION LAMBDA\_PT\_IGMIX(P,T,TYPE, COMP)**  
 For call from FORTRAN:  
**REAL\*8 P, T, COMP(0:30)  
 INTEGER\*4 TYPE**

Subprogram with parameter:  
**INTEGER\*4 FUNCTION  
 C\_LAMBDA\_PT\_IGMIX(LAMBDA,P,T,TYPE, COMP)**  
 For call from DLL:  
**REAL\*8 LAMBDA, P, T, COMP(0:30)  
 INTEGER\*4 TYPE**

### Input values:

P - Total pressure  $p$  in bar

T - Temperature  $t$  in °C

TYPE - Type of composition:  
 TYPE = 1 for the composition in mass fractions  $\xi$   
 TYPE = 0 for the composition in mole fractions  $\psi$

COMP(0:30) – Composition in mass fractions  $\xi_1 \dots \xi_{30}$  in kg / kg at TYPE = 1  
 – Composition in mole fractions  $\psi_1 \dots \psi_{30}$  in kmol / kmol at TYPE = 0  
 COMP(0) - dummy  
 COMP(1)...COMP(30) mass or mole fractions of the mixture gases  
 (see table of Combustion Gases)

### Result:

lambda\_pt\_igmix – Thermal conductivity  $\lambda$  in W/(m K)

### Range of validity:

Total pressure  $p$  : from 0.01 mbar to 50 bar

Temperature  $t$  : from -73.15 °C to 3026.85 °C  
 Exceptions: Propylene from -73.15 °C to 1500 °C  
 Fluorine from -73.15 °C to 976.8 °C

### Details:

Calculation according to Brandt [15] and VB [33] – model of the ideal mixture

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

**Molar Mass  $M = f(\xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$**

Function Name:	<b>M_igmix</b>
Subprogram with function value:	<b>REAL*8 FUNCTION M_IGMIX(TYPE, COMP)</b>
For call from FORTRAN:	REAL*8 COMP(0:30) INTEGER*4 TYPE
Subprogram with parameter:	<b>INTEGER*4 FUNCTION C_M_IGMIX(M,TYPE, COMP)</b>
For call from DLL:	REAL*8 M, COMP(0:30) INTEGER*4 TYPE

**Input values:**

TYPE	- Type of composition: TYPE = 1 for the composition in mass fractions $\xi$ TYPE = 0 for the composition in mole fractions $\psi$
COMP(0:30)	- Composition in mass fractions $\xi_1 \dots \xi_{30}$ in kg / kg at TYPE = 1 - Composition in mole fractions $\psi_1 \dots \psi_{30}$ in kmol / kmol at TYPE = 0 COMP(0) - dummy COMP(1)...COMP(30) mass or mole fractions of the mixture gases (see table of <u>Combustion Gases</u> )

**Result:**

M\_igmix - Molar mass  $M$  in kg/kmol

**Details:**

Calculation according to *Blanke*

**Results for wrong input values:**

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Kinematic Viscosity $\nu = f(p, t, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name: **ny\_pt\_igmix**

Subprogram with function value: **REAL\*8 FUNCTION NY\_PT\_IGMIX(P,T,TYPE, COMP)**  
 For call from FORTRAN: **REAL\*8 P, T, COMP(0:30)**  
**INTEGER\*4 TYPE**

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_NY\_PT\_IGMIX(NY,P,T,TYPE, COMP)**  
 For call from DLL: **REAL\*8 NY, P, T, COMP(0:30)**  
**INTEGER\*4 TYPE**

### Input values:

P - Total pressure  $p$  in bar

T - Temperature  $t$  in °C

TYPE - Type of composition:  
 $\text{TYPE} = 1$  for the composition in mass fractions  $\xi$   
 $\text{TYPE} = 0$  for the composition in mole fractions  $\psi$

COMP(0:30) – Composition in mass fractions  $\xi_1 \dots \xi_{30}$  in kg / kg at TYPE = 1  
– Composition in mole fractions  $\psi_1 \dots \psi_{30}$  in kmol / kmol at TYPE = 0  
COMP(0) - dummy  
COMP(1)...COMP(30) mass or mole fractions of the mixture gases  
(see table of Combustion Gases)

### Result:

ny\_pt\_igmix – Kinematic viscosity  $\nu$  in  $\text{m}^2 / \text{s}$

### Range of validity:

Total pressure  $p$  : from 0.01 mbar to 50 bar

Temperature  $t$  : from -73.15 °C to 3026.85 °C  
Exceptions: Propylene from -73.15 °C to 1500 °C  
Fluorine from -73.15 °C to 976.8 °C

### Details:

Kinematic viscosity

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Backward Function : $p = f(t, s, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name: **p\_ts\_igmix**

Subprogram with function value: **REAL\*8 FUNCTION P\_TS\_IGMIX(T,S,TYPE, COMP)**  
 For call from FORTRAN:  
**REAL\*8 P, T, COMP(0:30)**  
**INTEGER\*4 TYPE**

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_P\_TS\_IGMIX(P,T,S,TYPE, COMP)**  
 For call from DLL:  
**REAL\*8 P, T,S, COMP(0:30)**  
**INTEGER\*4 TYPE**

### input values:

T - Temperature  $t$  in °C

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

TYPE - Type of composition:  
 TYPE = 1 for the composition in mass fractions  $\xi$   
 TYPE = 0 for the composition in mole fractions  $\psi$

COMP(0:30) – Composition in mass fractions  $\xi_1 \dots \xi_{30}$  in kg / kg at TYPE = 1  
 – Composition in mole fractions  $\psi_1 \dots \psi_{30}$  in kmol / kmol at TYPE = 0  
 COMP(0) - dummy  
 COMP(1)...COMP(30) mass or mole fractions of the mixture gases  
 (see table of Combustion Gases)

### Result:

p\_ts\_igmix - Total pressure  $p$  in bar

### Range of validity:

Total pressure $p$ :	from 0.01 mbar to 50 bar
Temperature $t$ :	from 200 K to 3026.85 °C
Exceptions:	Propylene from -73.15 °C to 1500 °C Fluorine from -73.15 °C to 976.8 °C

### Details:

- Model of the ideal mixture in consideration of the dissociation effect above 500 °C
- Iteration of  $p$  from  $s = f(p, t, comp(0:30))$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Backward Function : $p = f(t, v, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name:	<b>p_tv_igmix</b>
Subprogram with function value:	<b>REAL*8 FUNCTION P_TV_IGMIX(T,V,TYPE, COMP)</b>
For call from FORTRAN:	REAL*8 T, V, COMP(0:30) INTEGER*4 TYPE
Subprogram with parameter:	<b>INTEGER*4 FUNCTION C_P_TV_IGMIX(P,T,V,TYPE, COMP)</b>
For call from DLL:	REAL*8 P, T, V, COMP(0:30) INTEGER*4 TYPE

### Input values:

T	- Temperature $t$ in °C
V	- Specific volume $v$ in m³/kg
TYPE	- Type of composition: TYPE = 1 for the composition in mass fractions $\xi$ TYPE = 0 for the composition in mole fractions $\psi$
COMP(0:30)	- Composition in mass fractions $\xi_1 \dots \xi_{30}$ in kg / kg at TYPE = 1 - Composition in mole fractions $\psi_1 \dots \psi_{30}$ in kmol / kmol at TYPE = 0 COMP(0) - dummy COMP(1)...COMP(30) mass or mole fractions of the mixture gases (see table of <u>Combustion Gases</u> )

### Result:

p\_tv\_igmix - Total pressure  $p$  in bar

### Range of validity:

Total pressure $p$ :	from 0.01 mbar to 50 bar
Temperature $t$ :	from 200 K to 3026.85 °C
Exceptions:	Propylene from -73.15 °C to 1500 °C Fluorine from -73.15 °C to 976.8 °C

### Details:

$$p = \frac{R \cdot T}{v}$$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## PRANDTL - Number $Pr = f(p, t, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name:

**Pr\_pt\_igmix**

Subprogram with function value:

**REAL\*8 FUNCTION PR\_PT\_IGMIX(P,T,TYPE, COMP)**

For call from FORTRAN:

REAL\*8 P, T, COMP(0:30)

INTEGER\*4 TYPE

Subprogram with parameter:

**INTEGER\*4 FUNCTION C\_PR\_PT\_IGMIX(PR,P,T,TYPE, COMP)**

For call from DLL:

REAL\*8 PR, P, T, COMP(0:30)

INTEGER\*4 TYPE

### Input values:

- P - Total pressure  $p$  in bar
  - T - Temperature  $t$  in °C
  - TYPE - Type of composition:
    - TYPE = 1 for the composition in mass fractions  $\xi$
    - TYPE = 0 for the composition in mole fractions  $\psi$
  - COMP(0:30) – Composition in mass fractions  $\xi_1 \dots \xi_{30}$  in kg / kg at TYPE = 1
    - Composition in mole fractions  $\psi_1 \dots \psi_{30}$  in kmol / kmol at TYPE = 0
    - COMP(0) - dummy
    - COMP(1)...COMP(30) mass or mole fractions of the mixture gases
- (see table of Combustion Gases)

### Result:

Pr\_pt\_igmix – PRANDTL number Pr

### Range of validity:

- Total pressure  $p$  : from 0.01 mbar to 50 bar
- Temperature  $t$  : from -73.15 °C to 3026.85 °C
  - Exceptions: Propylene from -73.15 °C to 1500 °C
  - Fluorine from -73.15 °C to 976.8 °C

### Details:

PRANDTL number

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Mole Fraction $\psi_i = f(i, \xi_1 \dots \xi_{30})$

Function Name: **psi\_igas\_xsi\_igmix**  
 Subprogram with function value: **REAL\*8 FUNCTION PSI\_IGAS\_XSI\_IGMIX(IGAS, COMP)**  
 For call from FORTRAN: **REAL\*8 COMP(0:30)**  
**INTEGER\*4 IGAS**  
 Subprogram with parameter: **INTEGER\*4 FUNCTION C\_PSI\_PT\_IGMIX(PSI,IGAS, COMP)**  
 For call from DLL: **REAL\*8 PSI, COMP(0:30)**  
**INTEGER\*4 IGAS**

### Input values:

IGAS - Gas number  
 COMP(0:30) - Composition in mole fractions  $\psi_1 \dots \psi_{30}$  in kmol / kmol at TYPE = 0  
 COMP(0) - dummy  
 COMP(1)...COMP(30) mass fractions of the mixture gases  
 (see table of Combustion Gases)

### Result:

psi\_igas\_xsi\_igmix – Mole fraction  $\psi_i$  in kmol/kmol

### Range of validity:

gas number IGAS : from 1 to 30; gas numbers 26 to 29 are not occupied

### Details:

$$\text{Mole fraction : } \psi_i = \frac{R_i}{\sum(\xi_i \cdot R_i)} \cdot \xi_i$$

### Results for wrong input values:

Error	Meaning
-9999	sum of the values entered $\xi_1 \dots \xi_{30} \neq 1$ gas numbers beyond the range of validity
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Specific Gas Constant $R = f(\xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name: **R\_igmix**

Subprogram with function value: **REAL\*8 FUNCTION R\_IGMIX(TYPE, COMP)**

For call from FORTRAN:  
REAL\*8 COMP(0:30)  
INTEGER\*4 TYPE

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_R\_IGMIX(R,TYPE, COMP)**

For call from DLL:  
REAL\*8 R, COMP(0:30)  
INTEGER\*4 TYPE

### Input values:

TYPE - Type of composition:

TYPE = 1 for the composition in mass fractions  $\xi$

TYPE = 0 for the composition in mole fractions  $\psi$

COMP(0:30) – Composition in mass fractions  $\xi_1 \dots \xi_{30}$  in kg / kg at TYPE = 1

– Composition in mole fractions  $\psi_1 \dots \psi_{30}$  in kmol / kmol at TYPE = 0

COMP(0) - dummy

COMP(1)...COMP(30) mass or mole fractions of the mixture gases

(see table of Combustion Gases)

### Result:

R\_igmix – Specific gas constant R in kJ/(kg K)

### Details:

$$\text{Specific gas constant : } R = \sum_i (\xi_i \cdot R_i) \quad \text{or} \quad R = \frac{1}{\sum_i (\psi_i / R_i)}$$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Density $\rho = f(p, t, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name:	<b>rho_pt_igmix</b>
Subprogram with function value:	<b>REAL*8 FUNCTION RHO_PT_IGMIX(P,T,TYPE, COMP)</b>
For call from FORTRAN:	REAL*8 P, T, COMP(0:30) INTEGER*4 TYPE
Subprogram with parameter:	<b>INTEGER*4 FUNCTION C_RHO_PT_IGMIX_SI(RHO,P,T,TYPE, COMP)</b>
For call from DLL:	REAL*8 RHO, P, T, COMP(0:30) INTEGER*4 TYPE

### Input values:

P	- Total pressure $p$ in bar
T	- Temperature $t$ in °C
TYPE	- Type of composition: TYPE = 1 for the composition in mass fractions $\xi$ TYPE = 0 for the composition in mole fractions $\psi$
COMP(0:30)	- Composition in mass fractions $\xi_1 \dots \xi_{30}$ in kg / kg at TYPE = 1 - Composition in mole fractions $\psi_1 \dots \psi_{30}$ in kmol / kmol at TYPE = 0 COMP(0) - dummy COMP(1)...COMP(30) mass or mole fractions of the mixture gases (see table of <u>Combustion Gases</u> )

### Result:

rho\_pt\_igmix – Density  $\rho$  in kg/m<sup>3</sup>

### Range of validity:

Total pressure $p$ :	from 0.01 mbar to 50 bar
Temperature $t$ :	from -73.15 °C to 3026.85 °C
Exceptions:	Propylene from -73.15 °C to 1500 °C Fluorine from -73.15 °C to 976.8 °C

### Details:

$$\text{Calculation: } \rho = \frac{p}{R \cdot T}$$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas numbers; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Specific Entropy $s = f(p, t, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name:	<b>s_pt_igmix</b>
Subprogram with function value:	<b>REAL*8 FUNCTION S_PT_IGMIX(P,T,TYPE, COMP)</b>
For call from FORTRAN:	REAL*8 P, T, COMP(0:30) INTEGER*4 TYPE
Subprogram with parameter:	<b>INTEGER*4 FUNCTION C_S_PT_IGMIX(S,P,T,TYPE, COMP)</b>
For call from DLL:	REAL*8 S, P, T, COMP(0:30) INTEGER*4 TYPE

### Input values:

P	- Total pressure $p$ in bar
T	- Temperature $t$ in °C
TYPE	- Type of composition: TYPE = 1 for the composition in mass fractions $\xi$ TYPE = 0 for the composition in mole fractions $\psi$
COMP(0:30)	- Composition in mass fractions $\xi_1 \dots \xi_{30}$ in kg / kg at TYPE = 1 - Composition in mole fractions $\psi_1 \dots \psi_{30}$ in kmol / kmol at TYPE = 0 COMP(0) - dummy COMP(1)...COMP(30) mass or mole fractions of the mixture gases (see table of <u>Combustion Gases</u> )

### Result:

s\_pt\_igmix – Specific entropy  $s$  in kJ/(kg K)

### Range of validity:

Total pressure $p$ :	from 0.01 mbar to 50 bar
Temperature $t$ :	from -73.15 °C to 3026.85 °C
Exceptions:	Propylene from -73.15 °C to 1500 °C Fluorine from -73.15 °C to 976.8 °C

### Details:

Model of the ideal mixture in consideration of the dissociation effect

above 500 °C and  $\psi_{H_2O} \geq 0.1$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Backward Function : Temperature $t = f(p, h, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name:	<b>t_ph_igmix</b>
Subprogram with function value:	<b>REAL*8 FUNCTION T_PH_IGMIX(P,H,TYPE, COMP)</b>
For call from FORTRAN:	REAL*8 P, T, COMP(0:30) INTEGER*4 TYPE
Subprogram with parameter:	<b>INTEGER*4 FUNCTION C_T_PH_IGMIX(T,P,H,TYPE, COMP)</b>
For call from DLL:	REAL*8 T, P, H, COMP(0:30) INTEGER*4 TYPE

**Input values:**

P	- Total pressure $p$ in bar
H	- Specific enthalpy $h$ in kJ/kg
TYPE	- Type of composition: TYPE = 1 for the composition in mass fractions $\xi$ TYPE = 0 for the composition in mole fractions $\psi$
COMP(0:30)	- Composition in mass fractions $\xi_1 \dots \xi_{30}$ in kg / kg at TYPE = 1 - Composition in mole fractions $\psi_1 \dots \psi_{30}$ in kmol / kmol at TYPE = 0 COMP(0) - dummy COMP(1)...COMP(30) mass or mole fractions of the mixture gases (see table of <u>Combustion Gases</u> )

**Result:**t\_ph\_igmix – Temperature  $t$  in °C**Range of validity:**

Total pressure $p$ :	from 0.01 mbar to 50 bar
Temperature $t$ :	from -73.15 °C to 3026.85 °C
Exceptions:	Propylene from -73.15 °C to 1500 °C Fluorine from -73.15 °C to 976.8 °C

**Details:**Iteration of  $t$  from  $h = f(p, t, \text{comp}(0:30))$ **Results for wrong input values:**

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Backward Function : Temperature $t = f(p, s, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name:	<b>t_ps_igmix</b>
Subprogram with function value:	<b>REAL*8 FUNCTION T_PS_IGMIX(P,S,TYPE, COMP)</b>
For call from FORTRAN:	REAL*8 P, T, COMP(0:30) INTEGER*4 TYPE
Subprogram with parameter:	<b>INTEGER*4 FUNCTION C_T_PS_IGMIX(T,P,S,TYPE, COMP)</b>
For call from DLL:	REAL*8 T, P, S, COMP(0:30) INTEGER*4 TYPE

**Input values:**

P	- Total pressure $p$ in bar
S	- Specific entropy $s$ in kJ/(kg K)
TYPE	- Type of composition: TYPE = 1 for the composition in mass fractions $\xi$ TYPE = 0 for the composition in mole fractions $\psi$
COMP(0:30)	- Composition in mass fractions $\xi_1 \dots \xi_{30}$ in kg / kg at TYPE = 1 - Composition in mole fractions $\psi_1 \dots \psi_{30}$ in kmol / kmol at TYPE = 0 COMP(0) - dummy COMP(1)...COMP(30) mass or mole fractions of the mixture gases (see table of <u>Combustion Gases</u> )

**Result:**t\_ps\_igmix – Temperature  $t$  in °C**Range of validity:**

Total pressure $p$ :	from 0.01 mbar to 50 bar
Temperature $t$ :	from -73.15 °C to 3026.85 °C
Exceptions:	Propylene from -73.15 °C to 1500 °C Fluorine from -73.15 °C to 976.8 °C

**Details:**Iteration of  $t$  from  $h = f(p, t, \text{comp}(0:30))$ **Results for wrong input values:**

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Backward Function : Temperature $t = f(p, v, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name:	<b>t_pv_igmix</b>
Subprogram with function value:	<b>REAL*8 FUNCTION T_PV_IGMIX(P,V,TYPE, COMP)</b>
For call from FORTRAN:	REAL*8 P, T, COMP(0:30) INTEGER*4 TYPE
Subprogram with parameter:	<b>INTEGER*4 FUNCTION C_T_PV_IGMIX(T,P,V,TYPE, COMP)</b>
For call from DLL:	REAL*8 T, P, V, COMP(0:30) INTEGER*4 TYPE

**Input values:**

P	- Total pressure $p$ in bar
V	- Specific volume $v$ in $\text{m}^3/\text{kg}$
TYPE	- Type of composition: TYPE = 1 for the composition in mass fractions $\xi$ TYPE = 0 for the composition in mole fractions $\psi$
COMP(0:30)	- Composition in mass fractions $\xi_1 \dots \xi_{30}$ in kg / kg at TYPE = 1 - Composition in mole fractions $\psi_1 \dots \psi_{30}$ in kmol / kmol at TYPE = 0 COMP(0) - dummy COMP(1)...COMP(30) mass or mole fractions of the mixture gases (see table of <u>Combustion Gases</u> )

**Result:**t\_pv\_igmix – Temperature  $t$  in  $^\circ\text{C}$ **Range of validity:**

Total pressure $p$ :	from 0.01 mbar to 50 bar
Temperature $t$ :	from $-73.15^\circ\text{C}$ to $3026.85^\circ\text{C}$
Exceptions:	Propylene from $-73.15^\circ\text{C}$ to $1500^\circ\text{C}$ Fluorine from $-73.15^\circ\text{C}$ to $976.8^\circ\text{C}$

**Details:**Iteration of  $t$  from  $h = f(p, t, \text{comp}(0:30))$ **Results for wrong input values:**

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Specific Internal Energy $u = f(p, t, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name: **u\_pt\_igmix**

Subprogram with function value: **REAL\*8 FUNCTION U\_PT\_IGMIX(P,T,TYPE, COMP)**  
 For call from FORTRAN:  
**REAL\*8 P, T, COMP(0:30)**  
**INTEGER\*4 TYPE**

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_U\_PT\_IGMIX(U,P,T,TYPE, COMP)**  
 For call from DLL:  
**REAL\*8 U, P, T, COMP(0:30)**  
**INTEGER\*4 TYPE**

### Input values:

P - Total pressure  $p$  in bar

T - Temperature  $t$  in °C

TYPE - Type of composition:  
 TYPE = 1 for the composition in mass fractions  $\xi$   
 TYPE = 0 for the composition in mole fractions  $\psi$

COMP(0:30) – Composition in mass fractions  $\xi_1 \dots \xi_{30}$  in kg / kg at TYPE = 1  
 – Composition in mole fractions  $\psi_1 \dots \psi_{30}$  in kmol / kmol at TYPE = 0  
 COMP(0) - dummy  
 COMP(1)...COMP(30) mass or mole fractions of the mixture gases  
 (see table of Combustion Gases)

### Result:

u\_pt\_igmix – Specific internal energy  $u$  in kJ/kg

### Range of validity:

Total pressure  $p$  : from 0.01 mbar to 50 bar

Temperature  $t$  : from -73.15 °C to 3026.85 °C  
 Exceptions: Propylene from -73.15 °C to 1500 °C  
 Fluorine from -73.15 °C to 976.8 °C

### Details:

Specific internal energy  $u$  from  $u = h(p,t,comp(0:30)) - R * T$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Specific Volume $v = f(p, t, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name: **v\_pt\_igmix**

Subprogram with function value: **REAL\*8 FUNCTION V\_PT\_IGMIX(P,T,TYPE, COMP)**  
 For call from FORTRAN:  
**REAL\*8 P, T, COMP(0:30)**  
**INTEGER\*4 TYPE**

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_V\_PT\_IGMIX(V,P,T,TYPE, COMP)**  
 For call from DLL:  
**REAL\*8 V, P, T, COMP(0:30)**  
**INTEGER\*4 TYPE**

### Input values:

P - Total pressure  $p$  in bar

T - Temperature  $t$  in °C

TYPE - Type of composition:  
 TYPE = 1 for the composition in mass fractions  $\xi$   
 TYPE = 0 for the composition in mole fractions  $\psi$

COMP(0:30) – Composition in mass fractions  $\xi_1 \dots \xi_{30}$  in kg / kg at TYPE = 1  
 – Composition in mole fractions  $\psi_1 \dots \psi_{30}$  in kmol / kmol at TYPE = 0  
 COMP(0) - dummy  
 COMP(1)...COMP(30) mass or mole fractions of the mixture gases  
 (see table of Combustion Gases)

### Result:

v\_pt\_igmix – Specific volume  $v$  in m<sup>3</sup>/kg

### Range of validity:

Total pressure  $p$  : from 0.01 mbar to 50 bar

Temperature  $t$  : from -73.15 °C to 3026.85 °C  
 Exceptions: Propylene from -73.15 °C to 1500 °C  
 Fluorine from -73.15 °C to 976.8 °C

### Details:

$$\text{Specific volume } v \text{ from } v = \frac{R_m \cdot T}{p}$$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Isentropic Speed of Sound $w = f(p, t, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$

Function Name:	<b>w_pt_igmix</b>
Subprogram with function value:	<b>REAL*8 FUNCTION W_PT_IGMIX(P,T,TYPE, COMP)</b>
For call from FORTRAN:	REAL*8 P, T, COMP(0:30) INTEGER*4 TYPE
Subprogram with parameter:	<b>INTEGER*4 FUNCTION C_W_PT_IGMIX(W,P,T,TYPE, COMP)</b>
For call from DLL:	REAL*8 W, P, T, COMP(0:30) INTEGER*4 TYPE

**Input values:**

P	- Total pressure $p$ in bar
T	- Temperature $t$ in °C
TYPE	- Type of composition: TYPE = 1 for the composition in mass fractions $\xi$ TYPE = 0 for the composition in mole fractions $\psi$
COMP(0:30)	- Composition in mass fractions $\xi_1 \dots \xi_{30}$ in kg / kg at TYPE = 1 - Composition in mole fractions $\psi_1 \dots \psi_{30}$ in kmol / kmol at TYPE = 0 COMP(0) - dummy COMP(1)...COMP(30) mass or mole fractions of the mixture gases (see table of <u>Combustion Gases</u> )

**Result:**

w\_pt\_igmix – Isentropic speed of sound  $w$  in m/s

**Range of validity:**

Total pressure $p$ :	from 0.01 mbar to 50 bar
Temperature $t$ :	from -73.15 °C to 3026.85 °C
Exceptions:	Propylene from -73.15 °C to 1500 °C Fluorine from -73.15 °C to 976.8 °C

**Details:**

Isentropic speed of sound  $w$  from :  $w = \sqrt{\frac{R_m \cdot T \cdot c_p}{c_p - R_m}}$   
 $c_p = f(p, t, \text{comp}(0:30))$

**Results for wrong input values:**

Error	Meaning
-9999	Input values beyond the range of validity and/or sum of the values entered $\xi_1 \dots \xi_{30}$ or $\psi_1 \dots \psi_{30} \neq 1$
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## Mass Fraction $\xi_i = f(i, \psi_1 \dots \psi_{30})$

Function Name:	<b>xsi_igas_psi_igmix</b>
Subprogram with function value:	<b>REAL*8 FUNCTION XSI_IGAS_PSI_IGMIX(IGAS, COMP)</b>
For call from FORTRAN:	REAL*8 COMP(0:30) INTEGER*4 IGAS
Subprogram with parameter:	<b>INTEGER*4 FUNCTION C_XSI_IGAS_PSI_IGMIX(XSI,IGAS, COMP)</b>
For call from DLL:	REAL*8 XSI, COMP(0:30) INTEGER*4 IGAS

### Input values:

IGAS	- Gas number
COMP(0:30)	<ul style="list-style-type: none"> <li>- Composition in mass fractions <math>\xi_1 \dots \xi_{30}</math> in kg / kg at TYPE = 1</li> <li>- Composition in mole fractions <math>\psi_1 \dots \psi_{30}</math> in kmol / kmol at TYPE = 0</li> </ul>
	COMP(0) - dummy
	COMP(1)...COMP(30) mass or mole fractions of the mixture gases (see table of <a href="#">Combustion Gases</a> )
	TYPE = 1 for the composition in mass fractions $\xi$
	TYPE = 0 for the composition in mole fractions $\psi$

### Result:

xsi\_igas\_psi\_igmix – Mass fraction  $\xi_i$  in kg/kg

### Range of validity:

Gas number IGAS: from 1 to 30; gas numbers 26 to 29 are not occupied

### Results for wrong input values:

Error	Meaning
-9999	sum of the values entered $\psi_1 \dots \psi_{30} \neq 1$ gas number beyond the range of validity
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied
-30777	Fluorine (F2) as a mixture gas

## 4. Program Documentation for Single Gases (igas-Functions)

### Thermal Diffusivity $a = f(p, t, \text{igas})$

Function Name: **a\_pt\_igas**

Subprogram with function value: **REAL\*8 FUNCTION A\_PT\_IGAS(P,T,IGAS)**

For call from FORTRAN:  
REAL\*8 P, T  
INTEGER\*4 IGAS

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_A\_PT\_IGAS(A,P,T,IGAS)**

For call from DLL:  
REAL\*8 A, P, T  
INTEGER\*4 IGAS

#### Input values:

P - Total pressure  $p$  in bar

T - Temperature  $t$  in °C

IGAS - Gas number (see table of [Combustion Gases](#))

#### Result:

a\_pt\_igas – Thermal diffusivity  $a$  in  $\text{m}^2 / \text{s}$

#### Range of validity:

Total pressure  $p$  : from 0.01 mbar to 50 bar

Temperature  $t$  : from -73.15 °C to 3026.85 °C

Exceptions: Propylene from -73.15 °C to 1500 °C

Fluorine from -73.15 °C to 976.8 °C

#### Details:

$$\text{Thermal diffusivity } a = \frac{\lambda}{\rho \cdot c_p}$$

#### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-xx999	xx...gas number; Gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Specific Isobaric Heat Capacity $c_p = f(p, t, \text{igas})$

Function Name: **cp\_pt\_igas**

Subprogram with function value: **REAL\*8 FUNCTION CP\_PT\_IGAS(P,T,IGAS)**

For call from FORTRAN:  
REAL\*8 P,T  
INTEGER\*4 IGAS

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_CP\_PT\_IGAS(CP,P,T,IGAS)**

For call from DLL:  
REAL\*8 CP, P,T  
INTEGER\*4 IGAS

### Input values:

P	- Total pressure $p$ in bar
T	- Temperature $t$ in °C
IGAS	- Gas number (see table of <u>Combustion Gases</u> )

### Result:

cp\_pt\_igas – Specific isobaric heat capacity  $c_p$  in kJ / (kg K)

### Range of validity:

Total pressure  $p$  : from 0.01 mbar to 50 bar

Temperature  $t$  : from -73.15 °C to 3026.85 °C

Exceptions: Propylene from -73.15 °C to 1500 °C

Fluorine from -73.15 °C to 976.8 °C

### Details:

Model of the ideal mixture in consideration of the dissociation effect  
above 500 °C and  $\psi_{H_2O} \geq 0.1$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Specific Isochoric Heat Capacity $c_v = f(p, t, \text{igas})$

Function Name:	<b>cv_pt_igas</b>
Subprogram with function value:	<b>REAL*8 FUNCTION CV_PT_IGAS(P,T,IGAS)</b>
For call from FORTRAN:	REAL*8 P,T INTEGER*4 IGAS
Subprogram with parameter:	<b>INTEGER*4 FUNCTION C_CV_PT_IGAS(CV,P,T,IGAS)</b>
For call from DLL:	REAL*8 CV, P,T INTEGER*4 IGAS

### Input values:

P	- Total pressure $p$ in bar
T	- Temperature $t$ in °C
IGAS	- Gas number (see table of <u>Combustion Gases</u> )

### Result:

cv\_pt\_igas – Specific isochoric heat capacity  $c_v$  in kJ / (kg K)

### Range of validity:

Total pressure $p$ :	from 0.01 mbar to 50 bar
Temperature $t$ :	from -73.15 °C to 3026.85 °C
Exceptions:	Propylene from -73.15 °C to 1500 °C Fluorine from -73.15 °C to 976.8 °C

### Details:

$$c_v = c_p - R$$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Dynamic Viscosity $\eta = f(p, t, \text{igas})$

Function Name: **eta\_pt\_igas**  
 Subprogram with function value: **REAL\*8 FUNCTION ETA\_PT\_IGAS(P,T,IGAS)**  
 For the call out of FORTRAN  
**REAL\*8 P,T**  
**INTEGER\*4 IGAS**

Subprogram with parameter:  
 For call from DLL:  
**INTEGER\*4 FUNCTION C\_ETA\_PT\_IGAS(ETA,P,T,IGAS)**  
**REAL\*8 ETA, P,T**  
**INTEGER\*4 IGAS**

### Input values:

P	- Total pressure $p$ in bar
T	- Temperature $t$ in °C
IGAS	- Gas number (see table of <u>Combustion Gases</u> )

### Result:

eta\_pt\_igas – Dynamic viscosity  $\eta$  in Pa s

### Range of validity:

Total pressure $p$ :	from 0.01 mbar to 50 bar
Temperature $t$ :	from -73.15 °C to 3026.85 °C
Exceptions:	Propylene from -73.15 °C to 1500 °C
	Fluorine from -73.15 °C to 976.8 °C

### Details:

Calculation according to *Brandt*[15] and *VB* [33] – model of the ideal mixture.

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Specific Enthalpy $h = f(p, t, \text{igas})$

Function Name: **h\_pt\_igas**

Subprogram with function value: **REAL\*8 FUNCTION H\_PT\_IGAS(P,T,IGAS)**

For the call out of FORTRAN  
REAL\*8 P,T  
INTEGER\*4 IGAS

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_H\_PT\_IGAS(H,P,T,IGAS)**

For call from DLL:  
REAL\*8 H, P,T  
INTEGER\*4 IGAS

### Input values:

P - Total pressure  $p$  in bar

T - Temperature  $t$  in °C

IGAS - Gas number (see table of [Combustion Gases](#))

### Result:

h\_pt\_igas – Specific enthalpy  $h$  in kJ/kg

### Range of validity:

Total pressure  $p$  : from 0.01 mbar to 50 bar

Temperature  $t$  : from -73.15 °C to 3026.85 °C

Exceptions: Propylene from -73.15 °C to 1500 °C

Fluorine from -73.15 °C to 976.8 °C

### Details:

Model of the ideal mixture in consideration of the dissociation effect

above 500 °C and  $\psi_{H_2O} \geq 0.1$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Isentropic Exponent $\kappa = f(p, t, \text{igas})$

Function Name:	<b>kappa_pt_igas</b>
Subprogram with function value:	<b>REAL*8 FUNCTION KAPPA_PT_IGAS(P,T,IGAS)</b>
For the call out of FORTRAN	REAL*8 P,T INTEGER*4 IGAS
Subprogram with parameter:	<b>INTEGER*4 FUNCTION C_KAPPA_PT_IGAS(KAPPA,P,T,IGAS)</b>
For call from DLL:	REAL*8 KAPPA, P,T INTEGER*4 IGAS

### Input values:

P	- Total pressure $p$ in bar
T	- Temperature $t$ in °C
IGAS	- Gas number (see table of <u>Combustion Gases</u> )

### Result:

kappa\_pt\_igas – Isentropic exponent  $\kappa$

### Range of validity:

Total pressure $p$ :	from 0.01 mbar to 50 bar
Temperature $t$ :	from -73.15 °C to 3026.85 °C
Exceptions:	Propylene from -73.15 °C to 1500 °C Fluorine from -73.15 °C to 976.8 °C

### Details:

$$\text{Kappa } \kappa = \frac{c_p}{c_p - R}$$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Thermal Conductivity $\lambda = f(p, t, \text{igas})$

Function Name:	<b>lambda_pt_igas</b>
Subprogram with function value:	<b>REAL*8 FUNCTION LAMBDA_PT_IGAS(P,T,IGAS)</b>
For the call out of FORTRAN	REAL*8 P,T INTEGER*4 IGAS
Subprogram with parameter:	<b>INTEGER*4 FUNCTION C_LAMBDA_PT_IGAS(LAMBDA,P,T,IGAS)</b>
For call from DLL:	REAL*8 LAMBDA, P,T INTEGER*4 IGAS

### Input values:

P	- Total pressure $p$ in bar
T	- Temperature $t$ in °C
IGAS	- Gas number (see table of <a href="#">Combustion Gases</a> )

### Result:

lambda\_pt\_igas – Isentropic exponent  $\lambda$  in W/(m K)

### Range of validity:

Total pressure $p$ :	from 0.01 mbar to 50 bar
Temperature $t$ :	from -73.15 °C to 3026.85 °C
Exceptions:	Propylene from -73.15 °C to 1500 °C Fluorine from -73.15 °C to 976.8 °C

### Details:

Calculation according to *Brandt*[15] and *VB* [33] – model of the ideal mixture.

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Molar Mass $M = f(p, t, \text{igas})$

Function Name: **M\_igas**

Subprogram with function value: **REAL\*8 FUNCTION M\_IGAS(IGAS)**  
For call from FORTRAN: **INTEGER\*4 IGAS**

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_M\_IGAS(M,IGAS)**  
For call from DLL: **REAL\*8 M**  
**INTEGER\*4 IGAS**

### Input values:

IGAS - Gas number (see table of [Combustion Gases](#))

### Result:

M\_igas – Molar mass  $M$  in kg/kmol

### Details:

Molar mass

### Results for wrong input values:

Error	Meaning
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Kinematic Viscosity $\nu = f(p, t, \text{igas})$

Function Name: **ny\_pt\_igas**  
 Subprogram with function value: **REAL\*8 FUNCTION NY\_PT\_IGAS(P,T,IGAS)**  
 For the call out of FORTRAN  
**REAL\*8 P,T**  
**INTEGER\*4 IGAS**

Subprogram with parameter:  
 For call from DLL:  
**INTEGER\*4 FUNCTION C\_NY\_PT\_IGAS(NY,P,T,IGAS)**  
**REAL\*8 NY, P, T**  
**INTEGER\*4 IGAS**

### Input values:

P	- Total pressure $p$ in bar
T	- Temperature $t$ in °C
IGAS	- Gas number (see table of <u>Combustion Gases</u> )

### Result:

ny\_pt\_igas – Kinematic viscosity  $\nu$  in  $\text{m}^2/\text{s}$

### Range of validity:

Total pressure $p$ :	from 0.01 mbar to 50 bar
Temperature $t$ :	from -73.15 °C to 3026.85 °C
Exceptions:	Propylene from -73.15 °C to 1500 °C
	Fluorine from -73.15 °C to 976.8 °C

### Details:

Kinematic viscosity

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Backward Function: Pressure $p = f(t, s, \text{igas})$

Function Name: **p\_ts\_igas**

Subprogram with function value: **REAL\*8 FUNCTION P\_TS\_IGAS\_SI(T,S,IGAS)**

For the call out of FORTRAN **REAL\*8 T,S**

**INTEGER\*4 IGAS**

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_P\_TS\_IGAS(P,T,S,IGAS)**

For call from DLL: **REAL\*8 P, T,S**

**INTEGER\*4 IGAS**

### Input values:

T - Temperature  $t$  in °C

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

IGAS - Gas number (see table of Combustion Gases)

### Result:

p\_ts\_igas - Total pressure  $p$  in bar

### Range of validity:

Total pressure  $p$  : from 0.01 mbar to 50 bar

Temperature  $t$  : from -73.15 °C to 3026.85 °C

Exceptions: Propylene from -73.15 °C to 1500 °C

Fluorine from -73.15 °C to 976.8 °C

### Details:

- Model of the ideal mixture in consideration of the dissociation effect above 500 °C

- Iteration of  $p$  from  $s = f(p,t)$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-7777	Result beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Backward Function: Pressure $p = f(t, v, \text{igas})$

Function Name: **p\_tv\_igas**

Subprogram with function value: **REAL\*8 FUNCTION P\_TV\_IGAS(T,V,IGAS)**

For call from FORTRAN:  
**REAL\*8 T, V**  
**INTEGER\*4 IGAS**

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_P\_TV\_IGAS(P,T,V,IGAS)**

For call from DLL:  
**REAL\*8 P, T, V**  
**INTEGER\*4 IGAS**

### Input values:

- |      |  |
|------|--|
| T    | - Temperature $t$ in °C                              |
| V    | - Specific volume $v$ in m <sup>3</sup> /kg          |
| IGAS | - Gas number (see table of <u>Combustion Gases</u> ) |

### Result:

p\_ts\_igas - Total pressure  $p$  in bar

### Range of validity:

- |                      |                                     |
|----------------------|-------------------------------------|
| Total pressure $p$ : | from 0.01 mbar to 50 bar            |
| Temperature $t$ :    | from -73.15 °C to 3026.85 °C        |
| Exceptions:          | Propylene from -73.15 °C to 1500 °C |
|                      | Fluorine from -73.15 °C to 976.8 °C |

### Details:

$$p = \frac{R \cdot T}{v}$$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-7777	Result beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## PRANDTL Number $Pr = f(p, t, \text{igas})$

Function Name: **Pr\_pt\_igas**

Subprogram with function value: **REAL\*8 FUNCTION PR\_PT\_IGAS(P,T,IGAS)**  
 For the call out of FORTRAN  
**REAL\*8 P,T**  
**INTEGER\*4 IGAS**

Subprogram with parameter:  
 For call from DLL:  
**INTEGER\*4 FUNCTION C\_PR\_PT\_IGAS(PR,P,T,IGAS)**  
**REAL\*8 PR, P,T**  
**INTEGER\*4 IGAS**

### Input values:

P	- Total pressure $p$ in bar
T	- Temperature $t$ in °C
IGAS	- Gas number (see table of <u>Combustion Gases</u> )

### Result:

Pr\_pt\_igas - PRANDTL number  $Pr$

### Range of validity:

Total pressure $p$ :	from 0.01 mbar to 50 bar
Temperature $t$ :	from -73.15 °C to 3026.85 °C
Exceptions:	Propylene from -73.15 °C to 1500 °C
	Fluorine from -73.15 °C to 976.8 °C

### Details:

PRANDTL number

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Specific Gas Constant $R = f(\text{igas})$

Function Name: **R\_igas**

Subprogram with function value: **REAL\*8 FUNCTION R\_IGAS(IGAS)**

For call from FORTRAN **INTEGER\*4 IGAS**

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_R\_IGAS(R,IGAS)**

For call from DLL: **REAL\*8 R**

**INTEGER\*4 IGAS**

### Input values:

IGAS - Gas number (see table of [Combustion Gases](#))

### Result:

R\_igas - Specific gas constant  $R$  in kJ/(kg K)

### Details:

$$\text{Specific gas constant : } R = \sum_i (\xi_i \cdot R_i) \quad \text{or} \quad R = \frac{1}{\sum_i (\psi_i / R_i)}$$

### Results for wrong input values:

Error	Meaning
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Density $\rho = f(p, t, \text{igas})$

Function Name: **`rho_pt_igas`**

Subprogram with function value: **`REAL*8 FUNCTION RHO_PT_IGAS(P,T,IGAS)`**  
 For the call out of FORTRAN  
`REAL*8 P,T`  
`INTEGER*4 IGAS`

Subprogram with parameter: **`INTEGER*4 FUNCTION C_RHO_PT_IGAS(RHO,P,T,IGAS)`**  
 For call from DLL:  
`REAL*8 RHO, P,T`  
`INTEGER*4 IGAS`

### Input values:

- |      |  |
|------|--|
| P    | - Total pressure $p$ in bar  |
| T    | - Temperature $t$ in °C  |
| IGAS | - Gas number (see table of <u><a href="#">Combustion Gases</a></u> ) |

### Result:

`rho_pt_igas` – Density  $\rho$  in kg/m<sup>3</sup>

### Range of validity:

- |                      |                                     |
|----------------------|-------------------------------------|
| Total pressure $p$ : | from 0.01 mbar to 50 bar            |
| Temperature $t$ :    | from -73.15 °C to 3026.85 °C        |
| Exceptions:          | Propylene from -73.15 °C to 1500 °C |
|                      | Fluorine from -73.15 °C to 976.8 °C |

### Details:

$$\text{Calculation: } \rho = \frac{p}{R \cdot T}$$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Specific Entropy $s = f(p, t, \text{igas})$

Function Name: **s\_pt\_igas**

Subprogram with function value: **REAL\*8 FUNCTION S\_PT\_IGAS(P,T,IGAS)**

For the call out of FORTRAN **REAL\*8 P,T**

**INTEGER\*4 IGAS**

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_S\_PT\_IGAS(S,P,T,IGAS)**

For call from DLL: **REAL\*8 S, P,T**

**INTEGER\*4 IGAS**

### Input values:

P - Total pressure  $p$  in bar

T - Temperature  $t$  in °C

IGAS - Gas number (see table of Combustion Gases)

### Result:

s\_pt\_igas – Specific entropy  $s$  in kJ/(kg K)

### Range of validity:

Total pressure  $p$  : from 0.01 mbar to 50 bar

Temperature  $t$  : from -73.15 °C to 3026.85 °C

Exceptions: Propylene from -73.15 °C to 1500 °C

Fluorine from -73.15 °C to 976.8 °C

### Details:

Model of the ideal mixture in consideration of the dissociation effect

above 500 °C and  $\psi_{H_2O} \geq 0.1$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Backward Function: Temperature $t = f(p, h, \text{igas})$

Function Name: **t\_ph\_igas**

Subprogram with function value: **REAL\*8 FUNCTION T\_PH\_IGAS(P,H,IGAS)**

For the call out of FORTRAN **REAL\*8 P,H**

**INTEGER\*4 IGAS**

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_T\_PH\_IGAS(T,P,H,IGAS)**

For call from DLL: **REAL\*8 T, P, H**

**INTEGER\*4 IGAS**

### Input values:

P - Total pressure  $p$  in bar

H - Specific enthalpy  $h$  in kJ/kg

IGAS - Gas number (see table of [Combustion Gases](#))

### Result:

t\_ph\_igas - Temperature  $t$  in °C

### Range of validity:

Total pressure  $p$  : from 0.01 mbar to 50 bar

Temperature  $t$  : from -73.15 °C to 3026.85 °C

Exceptions: Propylene from -73.15 °C to 1500 °C

Fluorine from -73.15 °C to 976.8 °C

### Details:

Iteration of  $t$  from  $h = f(p,t)$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-7777	Result beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Backward Function: Temperature $t = f(p, s, \text{igas})$

Function Name: **t\_ps\_igas**

Subprogram with function value: **REAL\*8 FUNCTION T\_PS\_IGAS(P,S,IGAS)**

For the call out of FORTRAN  
REAL\*8 P,S  
INTEGER\*4 IGAS

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_T\_PS\_IGAS(T,P,S,IGAS)**

For call from DLL:  
REAL\*8 T, P, S  
INTEGER\*4 IGAS

### Input values:

P - Total pressure  $p$  in bar

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

IGAS - Gas number (see table of [Combustion Gases](#))

### Result:

$t_{\text{ps\_igas}}$  - Temperature  $t$  in °C

### Range of validity:

Total pressure  $p$  : from 0.01 mbar to 50 bar

Temperature  $t$  : from -73.15 °C to 3026.85 °C

Exceptions: Propylene from -73.15 °C to 1500 °C

Fluorine from -73.15 °C to 976.8 °C

### Details:

Iteration of  $t$  from  $h = f(p,t)$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-7777	Result beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Backward Function: Temperature $t = f(p, v, \text{igas})$

Function Name: **t\_pv\_igas**

Subprogram with function value: **REAL\*8 FUNCTION T\_PV\_IGAS(P,V,IGAS)**

For the call out of FORTRAN **REAL\*8 P,V**

**INTEGER\*4 IGAS**

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_T\_PV\_IGAS(T,P,V,IGAS)**

For call from DLL: **REAL\*8 T, P, V**

**INTEGER\*4 IGAS**

### Input values:

P - Total pressure  $p$  in bar

V - Specific volume  $v$  in  $\text{m}^3/\text{kg}$

IGAS - Gas number (see table of [Combustion Gases](#))

### Result:

t\_pv\_igas - Temperature  $t$  in  $^\circ\text{C}$

### Range of validity:

Total pressure  $p$  : from 0.01 mbar to 50 bar

Temperature  $t$  : from  $-73.15\text{ }^\circ\text{C}$  to  $3026.85\text{ }^\circ\text{C}$

Exceptions: Propylene from  $-73.15\text{ }^\circ\text{C}$  to  $1500\text{ }^\circ\text{C}$

Fluorine from  $-73.15\text{ }^\circ\text{C}$  to  $976.8\text{ }^\circ\text{C}$

### Details:

Iteration of  $t$  from  $h = f(p,t)$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-7777	Result beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Specific Internal Energy $u = f(p, t, \text{igas})$

Function Name: **u\_pt\_igas**

Subprogram with function value: **REAL\*8 FUNCTION U\_PT\_IGAS(P,T,IGAS)**

For the call out of FORTRAN  
REAL\*8 P,T  
INTEGER\*4 IGAS

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_U\_PT\_IGAS(U,P,T,IGAS)**

For call from DLL:  
REAL\*8 U, P,T  
INTEGER\*4 IGAS

### Input values:

P - Total pressure  $p$  in bar

T - Temperature  $t$  in °C

IGAS - Gas number (see table of [Combustion Gases](#))

### Result:

u\_pt\_igas – Specific internal energy  $u$  in kJ/kg

### Range of validity:

Total pressure  $p$  : from 0.01 mbar to 50 bar

Temperature  $t$  : from -73.15 °C to 3026.85 °C

Exceptions: Propylene from -73.15 °C to 1500 °C

Fluorine from -73.15 °C to 976.8 °C

### Details:

Specific internal energy  $u$  from:  $u = h(p,t) - R * T$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Specific Volume $v = f(p, t, \text{igas})$

Function Name: **v\_pt\_igas**

Subprogram with function value: **REAL\*8 FUNCTION V\_PT\_IGAS(P,T,IGAS)**

For the call out of FORTRAN **REAL\*8 P,T**

**INTEGER\*4 IGAS**

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_V\_PT\_IGAS(V,P,T,IGAS)**

For call from DLL: **REAL\*8 V, P,T**

**INTEGER\*4 IGAS**

### Input values:

P - Total pressure  $p$  in bar

T - Temperature  $t$  in °C

IGAS - Gas number (see table of Combustion Gases)

### Result:

v\_pt\_igas – Specific volume  $v$  in  $\text{m}^3/\text{kg}$

### Range of validity:

Total pressure  $p$  : from 0.01 mbar to 50 bar

Temperature  $t$  : from -73.15 °C to 3026.85 °C

Exceptions: Propylene from -73.15 °C to 1500 °C

Fluorine from -73.15 °C to 976.8 °C

### Details:

$$\text{Specific volume } v \text{ from: } v = \frac{R_m \cdot T}{p}$$

### Results for wrong input values:

Error	Meaning
-9999	Input values beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Isentropic Speed of Sound $w = f(p, t, \text{igas})$

Function Name: **w\_pt\_igas**

Subprogram with function value: **REAL\*8 FUNCTION W\_PT\_IGAS(P,T,IGAS)**

For the call out of FORTRAN  
REAL\*8 P,T  
INTEGER\*4 IGAS

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_W\_PT\_IGAS(V,P,T,IGAS)**

For call from DLL:  
REAL\*f8 W, P,T  
INTEGER\*4 IGAS

### **Input values:**

P - Total pressure  $p$  in bar

T - Temperature  $t$  in °C

IGAS - Gas number (see table of Combustion Gases)

### **Result:**

w\_pt\_igas – Isentropic speed of sound  $w$  in m/s

### **Range of validity:**

Total pressure  $p$  : from 0.01 mbar to 50 bar

Temperature  $t$  : from -73.15 °C to 3026.85 °C

Exceptions: Propylene from -73.15 °C to 1500 °C

Fluorine from -73.15 °C to 976.8 °C

### **Details:**

Isentropic speed of sound  $w$  from :

$$w = \sqrt{\frac{R_m \cdot T \cdot c_p}{c_p - R_m}}$$

$$c_p = f(p, t)$$

### **Results for wrong input values:**

Error	Meaning
-9999	Input values beyond the range of validity
-xx999	xx...gas number; gas not in the gaseous state
-xx0999	xx...gas number; gas; gas numbers 26 to 29 not occupied

## Property Libraries for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

### Water and Steam

#### Library LibIF97

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

#### Library LibIF97\_META

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

### Humid Combustion Gas Mixtures

#### Library LibHuGas

Model: Ideal mixture of the real fluids:  
 $\text{CO}_2$  - Span, Wagner     $\text{H}_2\text{O}$  - IAPWS-95  
 $\text{O}_2$  - Schmidt, Wagner     $\text{N}_2$  - Span et al.  
 Ar - Tegeler et al.

and of the ideal gases:

$\text{SO}_2$ ,  $\text{CO}$ ,  $\text{Ne}$   
 (Scientific Formulation of Bücker et al.)

Consideration of:

- Dissociation from VDI 4670
- Poynting effect

### Humid Air

#### Library LibHuAir

Model: Ideal mixture of the real fluids:

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

Consideration of:

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

### Extremely Fast Property Calculations

Spline-Based Table Look-up Method (SBTL)

#### Library LibSBTL\_IF97

#### Library LibSBTL\_95

#### Library LibSBTL\_HuAir

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

### Carbon Dioxide Including Dry Ice

#### Library LibCO2

Formulation of Span and Wagner (1996)

### Seawater

#### Library LibSeaWa

IAPWS Industrial Formulation 2013

### Ice

#### Library LibICE

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

### Ideal Gas Mixtures

#### Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

Ar	NO	He	Propylene
Ne	$\text{H}_2\text{O}$	$\text{F}_2$	Propane
$\text{N}_2$	$\text{SO}_2$	$\text{NH}_3$	Iso-Butane
$\text{O}_2$	$\text{H}_2$	Methane	n-Butane
CO	$\text{H}_2\text{S}$	Ethane	Benzene
$\text{CO}_2$	OH	Ethylene	Methanol
Air			

Consideration of:

- Dissociation from the VDI Guideline 4670

#### Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

### Humid Air

#### Library ASHRAE LibHuAirProp

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

- Dry air
- Steam

Consideration of:

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

[www.ashrae.org/bookstore](http://www.ashrae.org/bookstore)

### Refrigerants

#### Ammonia

#### Library LibNH3

Formulation of Tillner-Roth et al. (1993)

#### R134a

#### Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

#### Iso-Butane

#### Library LibButane\_Iso

Formulation of Bücker and Wagner (2006)

#### n-Butane

#### Library LibButane\_n

Formulation of Bücker and Wagner (2006)

### Mixtures for Absorption Processes

#### Ammonia/Water Mixtures

#### Library LibAmWa

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

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

#### Water/Lithium Bromide Mixtures

#### Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

### Liquid Coolants

#### Liquid Secondary Refrigerants

#### Library LibSecRef

Liquid solutions of water with

$\text{C}_2\text{H}_6\text{O}_2$	Ethylene glycol
$\text{C}_3\text{H}_8\text{O}_2$	Propylene glycol
$\text{C}_2\text{H}_5\text{OH}$	Ethanol
$\text{CH}_3\text{OH}$	Methanol
$\text{C}_3\text{H}_8\text{O}_3$	Glycerol
$\text{K}_2\text{CO}_3$	Potassium carbonate
$\text{CaCl}_2$	Calcium chloride
$\text{MgCl}_2$	Magnesium chloride
$\text{NaCl}$	Sodium chloride
$\text{C}_2\text{H}_3\text{KO}_2$	Potassium acetate
$\text{CHKO}_2$	Potassium formate
$\text{LiCl}$	Lithium chloride
$\text{NH}_3$	Ammonia

Formulation of the International Institute of Refrigeration (IIR 2010)

## Ethanol

### Library LibC2H5OH

Formulation of Schroeder et al. (2014)

## Methanol

### Library LibCH3OH

Formulation of de Reuck and Craven (1993)

## Propane

### Library LibPropane

Formulation of Lemmon et al. (2009)

## Siloxanes as ORC Working Fluids

Octamethylcyclotetrasiloxane  $C_8H_{24}O_4Si_4$  Library LibD4

Decamethylcyclopentasiloxane  $C_{10}H_{30}O_5Si_5$  Library LibD5

Tetradecamethylhexasiloxane  $C_{14}H_{42}O_5Si_6$  Library LibMD4M

Hexamethyldisiloxane  $C_6H_{18}OSi_2$  Library LibMM

Formulation of Colonna et al. (2006)

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

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

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

Octamethyltrisiloxane  $C_8H_{24}O_2Si_3$  Library LibMDM

Formulation of Colonna et al. (2008)

## Nitrogen and Oxygen

### Libraries

#### LibN2 and LibO2

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

## Hydrogen

### Library LibH2

Formulation of Leachman et al. (2009)

## Helium

### Library LibHe

Formulation of Arp et al. (1998)

## Hydrocarbons

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

Isopentane  $C_5H_{12}$  Library LibC5H12\_Iso

Neopentane  $C_5H_{12}$  Library LibC5H12\_Neo

Isohexane  $C_6H_{14}$  Library LibC6H14

Toluene  $C_7H_8$  Library LibC7H8

Formulation of Lemmon and Span (2006)

## Further Fluids

Carbon monoxide  $CO$  Library LibCO

Carbonyl sulfide  $COS$  Library LibCOS

Hydrogen sulfide  $H_2S$  Library LibH2S

Nitrous oxide  $N_2O$  Library LibN2O

Sulfur dioxide  $SO_2$  Library LibSO2

Acetone  $C_3H_6O$  Library LibC3H6O

Formulation of Lemmon and Span (2006)



## For more information please contact:

KCE-ThermoFluidProperties UG & Co. KG

Prof. Dr. Hans-Joachim Kretzschmar

Wallotstr. 3

01307 Dresden, Germany

Internet: [www.thermofluidprop.com](http://www.thermofluidprop.com)

Email: [info@thermofluidprop.com](mailto:info@thermofluidprop.com)

Phone: +49-351-27597860

Mobile: +49-172-7914607

Fax: +49-3222-1095810

## The following thermodynamic and transport properties can be calculated<sup>a</sup>:

### Thermodynamic Properties

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

### Transport Properties

- Dynamic viscosity  $\eta$
- Kinematic viscosity  $\nu$
- Thermal conductivity  $\lambda$
- Prandtl number  $Pr$
- Thermal diffusivity  $a$

### Backward Functions

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

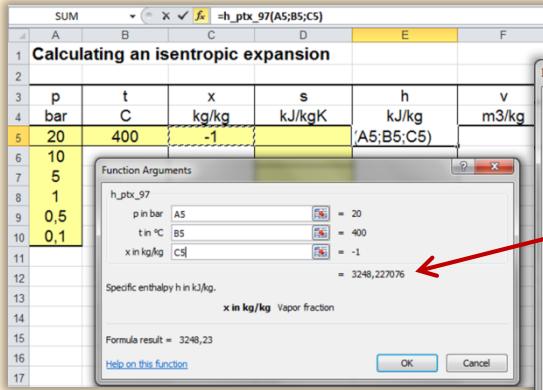
### Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

<sup>a</sup> Not all of these property functions are available in all property libraries.

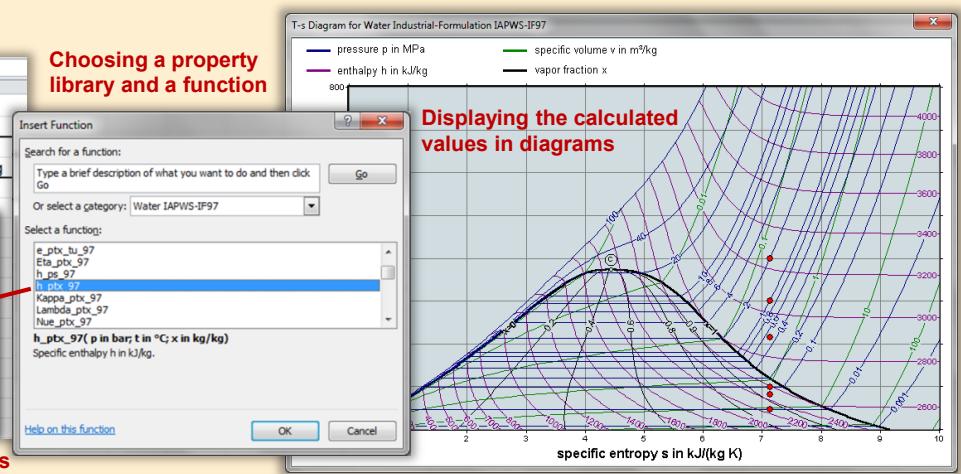
## Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

### Add-In FluidEXL Graphics for Excel®



Menu for the input of given property values

Choosing a property library and a function

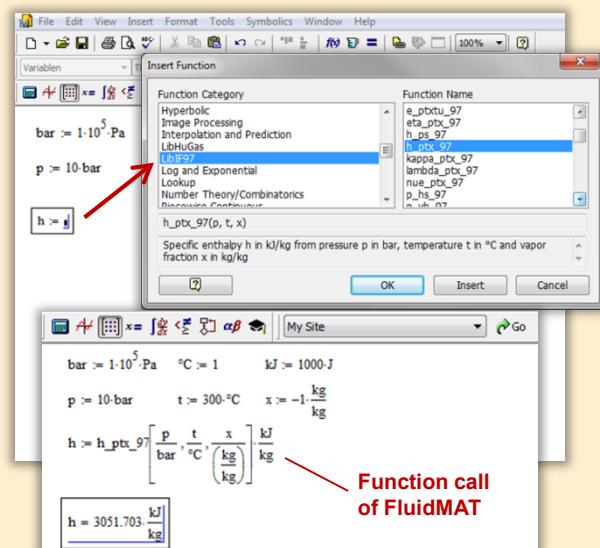


Displaying the calculated values in diagrams

### Add-On FluidMAT for Mathcad®

### Add-On FluidPRIME for Mathcad Prime®

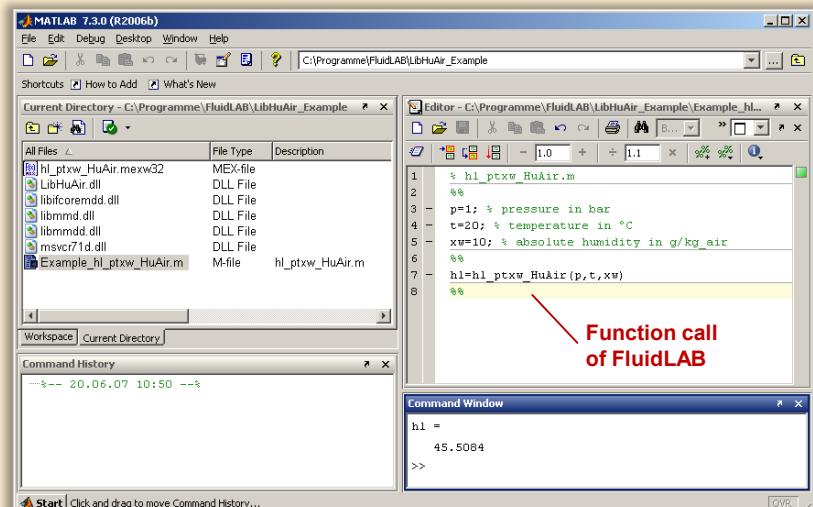
The property libraries can be used in Mathcad® and Mathcad Prime®.



Function call of FluidMAT

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

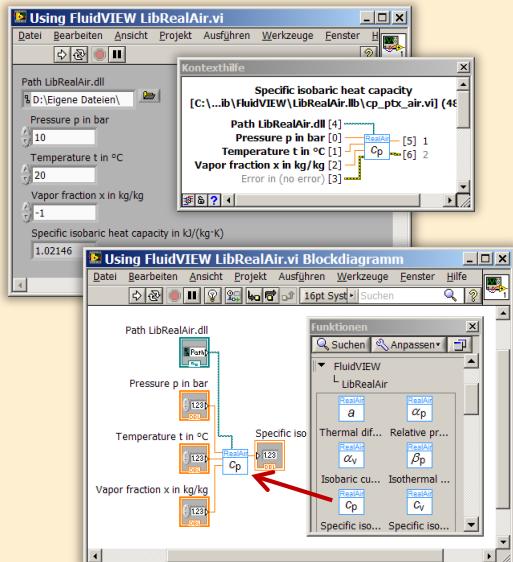
Using the Add-In FluidLAB the property functions can be called in MATLAB® and SIMULINK®.



Function call of FluidLAB

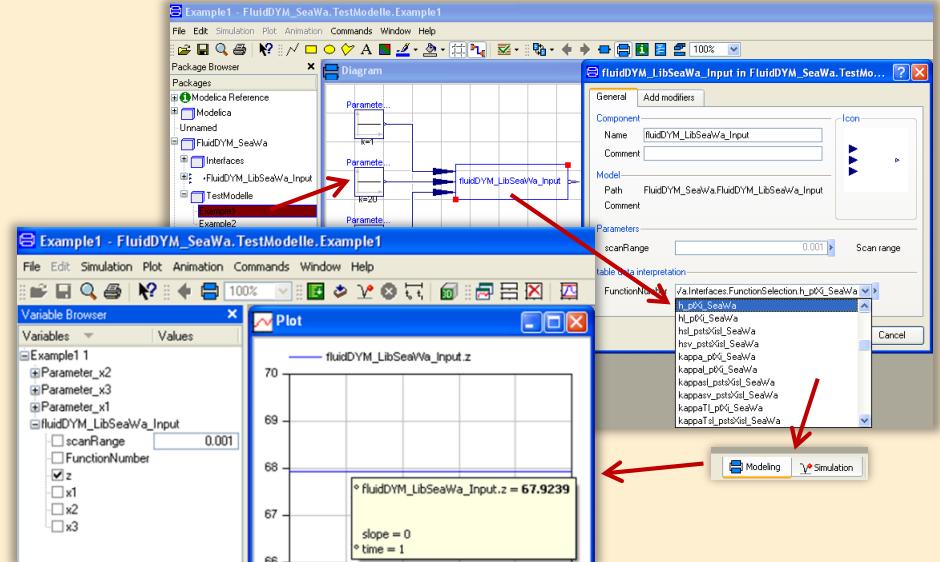
### Add-On FluidVIEW for LabVIEW™

The property functions can be calculated in LabVIEW™.

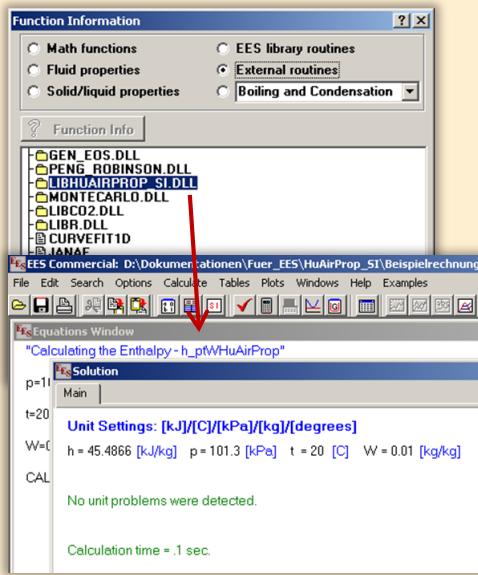


### Add-On FluidDYM for DYMOLA® (Modelica) and SimulationX®

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



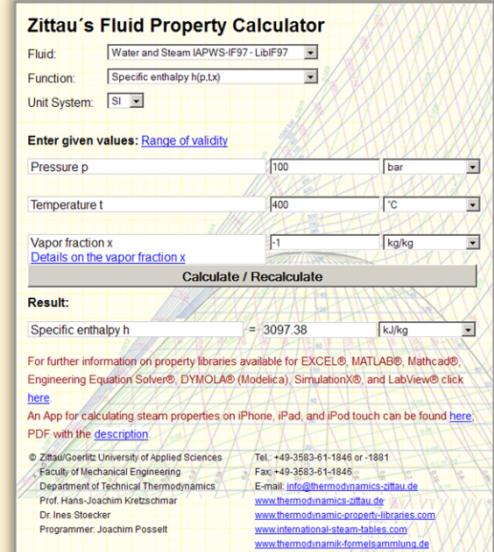
## Add-On FluidEES for Engineering Equation Solver®



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



## Online Property Calculator at [www.thermofluidprop.com](http://www.thermofluidprop.com)



## Property Software for Pocket Calculators

### FluidCasio



### FluidHP



### FluidTI



## For more information please contact:



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

Internet: [www.thermofluidprop.com](http://www.thermofluidprop.com)  
Email: [info@thermofluidprop.com](mailto:info@thermofluidprop.com)  
Phone: +49-351-27597860  
Mobile: +49-172-7914607  
Fax: +49-3222-1095810

The following thermodynamic and transport properties<sup>a</sup> can be calculated in Excel®, MATLAB®, Mathcad®, Engineering Equation Solver® (EES), DYMOLA® (Modelica), SimulationX® and LabVIEW™:

### Thermodynamic Properties

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

### Transport Properties

- Dynamic viscosity  $\eta$
- Kinematic viscosity  $\nu$
- Thermal conductivity  $\lambda$
- Prandtl number  $Pr$
- Thermal diffusivity  $a$

### Backward Functions

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

### Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

<sup>a</sup> Not all of these property functions are available in all property libraries.

## 6. References

- [1] IAPWS Secretariat, Dooley, B., EPRI, Palo Alto CA (1997):  
*Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam IAPWS-IF97.*
- [2] Wagner, W.; Cooper, J.R.; Dittmann, A.; Kijima, J.; Kretzschmar, H.-J.; Kruse, A.; Mareš, R.; Oguchi, K.; Sato, H.; Stöcker, I.; Šifner, O.; Takaishi, Y.; Tanishita, I.; Trübenbach, J.; Willkommen, Th. (2000):  
*The IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam.*  
ASME Journal of Engineering for Gas Turbines and Power 122, No. 1, pp. 150-182.
- [3] Wagner, W.; Kruse, A. (1998):  
*Properties of Water and Steam.*  
Springer-Verlag, Berlin
- [4] Kretzschmar, H.-J.; Stöcker, I.; Klinger, J.; Dittmann, A. (2000):  
Calculation of Thermodynamic Derivatives for Water and Steam Using the New Industrial Formulation IAPWS-IF97.  
in: *Steam, Water and Hydrothermal Systems: Physics and Chemistry Meeting the Needs of Industry, Proceedings of the 13th International Conference on the Properties of Water and Steam.* Eds. P.G. Hill et al., NRC Press, Ottawa
- [5] Kretzschmar, H.-J. (1998):  
*Mollier h-s Diagram.*  
Springer-Verlag, Berlin
- [6] IAPWS Secretariat, Dooley, B., EPRI, Palo Alto CA, (1997):  
*Revised Release on the IAPS Formulation 1985 for the Thermal Conductivity of Ordinary Water Substance.*
- [7] IAPWS Secretariat, Dooley, B., EPRI, Palo Alto CA, (1997):  
*Revised Release on the IAPS Formulation 1985 for the Viscosity of Ordinary Water Substance.*
- [8] IAPWS Secretariat, Dooley, B., EPRI, Palo Alto CA, (1994):  
*IAPWS Release on Surface Tension of Ordinary Water Substance 1994.*
- [9] Kretzschmar, H.-J.; Stöcker, I.; Willkommen, Th.; Trübenbach, J.; Dittmann, A. (2000):  
Supplementary Equations  $v(p, T)$  for the Critical Region to the New Industrial Formulation IAPWS-IF97 for Water and Steam.  
in: *Steam, Water and Hydrothermal Systems: Physics and Chemistry Meeting the Needs of Industry, Proceedings of the 13th International Conference on the Properties of Water and Steam.* Eds. P.G. Hill et al., NRC Press, Ottawa.
- [10] Kretzschmar, H.-J.; Stöcker, I.; Knobloch, K.; Trübenbach, J.; Willkommen, Th.; Dittmann, A.; Friend, D.G.:  
*Supplementary Backward Equations for Pressure as a Function of Enthalpy and Entropy  $p(h,s)$  to the Industrial Formulation IAPWS-IF97 for Water and Steam.*  
ASME Journal of Engineering for Gas Turbines and Power - in preparation

- [11] IAPWS Secretariat, Dooley, B., EPRI, Palo Alto CA, (1995):  
*Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use.*
- [12] Grigull, U. (1989):  
*Properties of Water and Steam in SI Units.*  
 Springer-Verlag, Berlin.
- [13] Kretzschmar, H.-J. (1990):  
*Zur Aufbereitung und Darbietung thermophysikalischer Stoffdaten für die Energietechnik (Preparation of Thermophysical Properties for Power Engineering).*  
 Habilitation. Dresden University of Technology, Faculty of Mechanical Engineering, Germany
- [14] Baehr, H.D.; Diederichsen, Ch. (1988):  
*Berechnungsgleichungen für Enthalpie und Entropie der Komponenten von Luft und Verbrennungsgasen (Equations for the Enthalpy and Entropy of Components of Air and Combustion Gases).*  
 BWK 40 (1988), no. 1/2, pp. 30-33.
- [15] Brandt, F. (1985):  
*Wärmeübertragung in Dampferzeugern und Wärmetauschern (Heat Transfer in Steam Generators and Heat Exchangers).*  
 FDBR-Fachbuchreihe, Bd. 2, Vulkan Verlag, Essen.
- [16] Bücker, D.; Span, R.; Wagner, W. (2002):  
*Thermodynamic Property Models of Moist Air Flue Gases.*  
 J. Phys. Chem. Ref. Data 29 – submitted.
- [17] Reid, R. C.; Prausnitz, J. M.; Poling, B. E. (1987):  
*The Properties of Gases and Liquids.*  
 4<sup>th</sup> Edition, McGraw-Hill Book Company, New York.
- [18] IAPWS Secretariat, Dooley, B., EPRI, Palo Alto CA, (1975):  
*Release on Surface Tension of Ordinary Water Substance 1975.*
- [19] VDI Wärmeatlas, 1995, 7<sup>th</sup> Edition  
 VDI-Verlag, Düsseldorf.
- [20] Blanke, W. (1989):  
*Thermophysikalische Stoffgrößen (Thermophysical Properties).*  
 Springer-Verlag, Berlin.
- [21] VDI-Richtlinie 4670  
*Thermodynamische Stoffwerte von feuchter Luft und Verbrennungsgasen (VDI 4670 Guideline – Thermodynamic Properties of Humid Air and Combustion Gases).*  
 VDI Manual for Energy Technology, VDI Society for Energy Technology, Düsseldorf (2000).
- [22] Lemmon, E. W.; Jacobsen, R. T.; Penoncello, S. G.; Friend, D. G. (2000):  
*Thermodynamic Properties of Air and Mixtures of Nitrogen, Argon and Oxygen from 60 to 2000 K at Pressures to 2000 MPa.*  
 J. Phys. Chem. Ref. Data 29. Nr. 2, S. 331-385

- [23] Lemmon, E. W.; Jacobsen, R. T. (2000):  
*Transport Properties of Air.*  
 National Institute of Standards and Technology, Boulder CO. Private communication.
- [24] IAPWS Secretariat, Dooley, B, EPRI, Alto CA (1992):  
*Revised Supplementary Release on Saturation Properties of Ordinary Water Substance.*
- [25] Hyland, R. W.; Wexler, A. (1983):  
*Formulations for the Thermodynamic Properties of Saturated Phases of H<sub>2</sub>O from 173.15 K to 473.15 K.*  
 Report No. 2793 (RP-216), National Bureau of Standards, Washington, D.C.
- [26] de Reuck, K. M.; Craven, R. J. B. (1993):  
*Methanol. International Thermodynamic Tables of the Fluid State - 12.*  
 Blackwell Scientific Publications, London.
- [27] Wagner, W.; de Reuck, K. M. (1996):  
*Methane. International Thermodynamic Tables of the Fluid State - 13.*  
 Blackwell Scientific Publications, London.
- [28] de Reuck, K. M. (1990):  
*Fluorine. International Thermodynamic Tables of the Fluid State - 11.*  
 Blackwell Scientific Publications, London.
- [29] Buecker, D. (2003):  
*Neue Fundamentalgleichungen als Referenz für die thermodynamischen Zustandsgrößen von Ethan, n-Butan und Isobutan.*  
 Fortschr.-Ber. VDI, Reihe 6, Nr. 499, VDI Verlag, Düsseldorf.
- [30] Vargaftik, N. B.; Vinogradov, Y. K.; Yagarin, V. S. (1996):  
*Handbook of Physical Properties of Liquids and Gases.*  
 Revised Edition. Begell House, New York.
- [31] Span, R. (2000):  
*Multiparameter Equations of State. An Accurate Source of Thermodynamic Property Data.*  
 Springer-Verlag, Berlin.
- [32] Angus, S.; Armstrong, B.; de Reuck, K. M. (1978):  
*Final Report on IUPAC Propylene (Propene) Tables, Part 1: Text,*  
*International Thermodynamic Tables of the Fluid State – 7.*  
 Imperial College London, IUPAC Thermodynamic Tables Project Centre.
- [33] *Verfahrenstechnische Berechnungsmethoden, Teil 7: Stoffwerte (Process-Related Calculation Techniques, Part 7: Properties).*  
 Deutscher Verlag für Grundstoffindustrie, Leipzig (1981)
- [34] *Brennstofftechnische Arbeitsmappe (Combustion-Related Working Paper).*  
 Bergakademie Freiberg (1988)
- [35] Smukala, J.; Span, R.; Wagner, W. (2000):  
*New Equation for Ethylene Covering The Fluid Region for Temperatures From the Melting Line to 450 K at Pressures up to 300 MPa.*  
 Journal of Physical and Chemical Reference Data, Vol. 29, No. 5, pp. 1053-1121.

- [36] Span, R.; Wagner, W. (1996):  
*A New Equation of State for Carbon Dioxide Covering the Fluid Region from the Triple-Point Temperature to 1100K at Pressures up to 800 MPa.*  
 Journal of Physical and Chemical Reference Data, Vol. 25, No.6, pp. 1509-1596.
- [37] Younglove, B. A. (1982):  
*Thermophysical Properties of Fluids. I. Argon, Ethylene, Parahydrogen, Nitrogen, Nitrogen Trifluoride, and Oxygen.*  
 Journal of Physical and Chemical Reference Data, Vol. 11, Supplement No.1.
- [38] Baehr, H. D.; Tillner-Roth, R. (1995):  
*Thermodynamische Eigenschaften umweltverträglicher Kältemittel (Thermodynamic Properties of Environmentally Acceptable Refrigerants).*  
 Springer-Verlag, Berlin
- [39] Wagner, W.; Saul, A.; Pruss, A. (1994):  
*International Equations for the Pressure along the Melting And along the Sublimation Curve of Ordinary Water Substance.*  
 Journal of Physical and Chemical Reference Data. Vol.23, No. 3, pp. 515-527.
- [40] ASME Standards Technology, LLC:  
 Thermophysical Properties of Working Gases used in Turbine Applications.  
 STP-TS-012 (2008)
- [41] Lemmon, E.W.; Span, R.:  
 Short Fundamental Equations of State for 20 Industrial Fluids.  
 J. Chem. Eng. Data, 51:785-850, 2006
- [42] Overhoff, U.:  
 Development of a new equation of state for the fluid region of propene for temperatures from the melting line to 575 K with pressures to 1000 MPa as well as software for the computation of thermodynamic properties of fluids.  
 Ph.D. Dissertation, Ruhr University, Bochum, Germany, 2006
- [43] Lemmon, E.W.; McLinden, M.O.; Wagner, W.:  
 Thermodynamic Properties of Propane. IV. A Reference Equation of State for Temperatures from the Melting Line to 650 K and Pressures up to 1000 MPa.  
 to be submitted to J. Phys. Chem. Ref. Data, 2009
- [44] Polt, A.; Platzer, B.; Maurer, G.:  
 Parameter der thermischen Zustandsgleichung von Bender fuer 14 mehratomige reine Stoffe.  
 Chem. Tech. (Leipzig), 44(6):216-224, 1992
- [45] Leachman, J.W.; Jacobsen, R.T.; Lemmon, E.W.:  
 Fundamental Equations of State for Parahydrogen, Normal Hydrogen, and Orthohydrogen.  
 to be published in the International Journal of Thermophysics, 2007
- [46] Kunz, O.; Klimeck, R.; Wagner, W.; Jaeschke, M.:  
 The GERG-2004 Wide-Range Reference Equation of State for Natural Gases and Other Mixtures.  
 Fortschr.-Ber. VDI, VDI-Verlag, Düsseldorf, 2006

## 7. Satisfied Customers

Date: 07/2019

The following companies and institutions use the property libraries:

- FluidEXL<sup>Graphics</sup> for Excel®
- FluidLAB for MATLAB® and Simulink
- FluidMAT for Mathcad®
- FluidPRIME for Mathcad Prime®
- FluidEES for Engineering Equation Solver® EES
- FluidDYM for Dymola® (Modelica) and SimulationX®
- FluidVIEW for LabVIEW™
- DLLs for Windows™
- Shared Objects for Linux®.

### 2019

WARNICA, Waterloo, Canada	07/2019
MIBRAG, Zeitz	06/2019
Pöry, Zürich, Switzerland	06/2019
RWTH Aachen, Inst. Strahlantriebe und Turbomaschinen	06/2019
Midiplan, Bietigheim-Bissingen	06/2019
GKS Schweinfurt	06/2019
HS Zittau/Görlitz, Wirtschaftswissenschaften und Wirtschaftsingenieurwesen	06/2019
ILK Dresden	06/2019
HZDR Helmholtz Zentrum Dresden-Rossendorf	06/2019
TH Köln, TGA	05/2019
IB Knittel, Braunschweig	05/2019
Norsk Energi, Oslo, Norway	05/2019
STEAG Essen	05/2019
Stora Enso, Eilenburg	05/2019
IB Lücke, Paderborn	05/2019
Haarslev, Sonderso, Denmark	05/2019
MAN Augsburg	05/2019
Wieland Werke, Ulm	04/2019
Fels-Werke, Elbingerode	04/2019
Univ. Luxembourg Luxembourg	04/2019
BTU Cottbus, Power Engineering	03/2009
Eins-Energie Sachsen, Schwarzenberg	03/2019
TU Dresden, Kälte- und Kryotechnik	03/2019
ITER, St. Paul Lez Durance Cedex, France	03/2019
Fraunhofer UMSICHT, Oberhausen	03/2019
Comparex Leipzig for Spedition Thiele HEMMERSBACH	03/2019
Rückert NaturGas, Lauf/Pegnitz	03/2019
BASF, Basel, Switzerland	02/2019
Stadtwerke Leipzig	02/2019

Maerz Ofenbau Zürich, Switzerland	02/2019
Hanon Systems Germany, Kerpen	02/2019
Thermofin, Heinsdorfergrund	01/2019
BSH Berlin	01/2019

## 2018

Jaguar Energy, Guatemala	12/2018
WEBASTO, Gilching	12/2018
Smurfit Kappa, Oosterhout, Netherlands	12/2018
Univ. BW München	12/2018
RAIV, Liberec for VALEO, Prague, Czech Republic	11/2018
VPC Group Vetschau	11/2018
SEITZ, Wetzikon, Switzerland	11/2018
MVV, Mannheim	10/2018
IB Troche	10/2018
KANIS Turbinen, Nürnberg	10/2018
TH Ingolstadt, Institut für neue Energiesysteme	10/2018
IB Kristl & Seibt, Graz, Austria	09/2018
INEOS, Köln	09/2018
IB Lücke, Paderborn	09/2018
Südzucker, Ochsenfurt	08/2018
K&K Turbinenservice, Bielefeld	07/2018
OTH Regensburg, Elektrotechnik	07/2018
Comparex Leipzig for LEAG, Berlin	06/2018
Münstermann, Telgte	05/2018
TH Nürnberg, Verfahrenstechnik	05/2018
Universität Madrid, Madrid, Spanien	05/2018
HS Zittau/Görlitz, Wirtschaftswissenschaften und Wirtschaftsingenieurwesen	05/2018
HS Niederrhein, Krefeld	05/2018
Wilhelm-Büchner HS, Pfungstadt	03/2018
GRS, Köln	03/2018
WIB, Dennheritz	03/2018
RONAL AG, Häcklingen, Schweiz	02/2018
Ingenieurbüro Leipert, Riegelsberg	02/2018
AIXPROCESS, Aachen	02/2018
KRONES, Neutraubling	02/2018
Doosan Lentjes, Ratingen	01/2018

## 2017

Compact Kältetechnik, Dresden	12/2017
Endress + Hauser Messtechnik GmbH +Co. KG, Hannover	12/2017
TH Mittelhessen, Gießen	11/2017
Haarslev Industries, Søndersø, Denmark	11/2017
Hochschule Zittau/Görlitz, Fachgebiet Energiesystemtechnik	11/2017
ATESTEO, Alsdorf	10/2017
Wijbenga, PC Geldermalsen, Netherlands	10/2017
Fels-Werke GmbH, Elbingerode	10/2017

KIT Karlsruhe, Institute für Neutronenphysik und Reaktortechnik	09/2017
Air-Consult, Jena	09/2017
Papierfabrik Koehler, Oberkirch	09/2017
ZWILAG, Würenlingen, Switzerland	09/2017
TLK-Thermo Universität Braunschweig, Braunschweig	08/2017
Fichtner IT Consulting AG, Stuttgart	07/2017
Hochschule Ansbach, Ansbach	06/2017
RONAL, Härkingen, Switzerland	06/2017
BORSIG Service, Berlin	06/2017
BOGE Kompressoren, Bielefeld	06/2017
STEAG Energy Services, Zwingenberg	06/2017
CES clean energy solutions, Wien, Austria	04/2017
Princeton University, Princeton, USA	04/2017
B2P Bio-to-Power, Wadersloh	04/2017
TU Dresden, Institute for Energy Engineering, Dresden	04/2017
SAINT-GOBAIN, Vaujours, France	03/2017
TU Bergakademie Freiberg, Chair of Thermodynamics, Freiberg	03/2017
SCHMIDT + PARTNER, Therwil, Switzerland	03/2017
KAESER Kompressoren, Gera	03/2017
F&R, Praha, Czech Republic	03/2017
ULT Umwelt-Lufttechnik, Löbau	02/2017
JS Energie & Beratung, Erding	02/2017
Kelvion Brazed PHE, Nobitz-Wilchwitz	02/2017
MTU Aero Engines, München	02/2017
Hochschule Zittau/Görlitz, IPM	01/2017
CombTec ProCE, Zittau	01/2017
SHELL Deutschland Oil, Wesseling	01/2017
MARTEC Education Center, Frederikshaven, Denmark	01/2017
SynErgy Thermal Management, Krefeld	01/2017

## 2016

BOGE Druckluftsysteme, Bielefeld	12/2016
BFT Planung, Aachen	11/2016
Midiplan, Bietigheim-Bissingen	11/2016
BBE Barnich IB	11/2016
Wenisch IB,	11/2016
INL, Idaho Falls	11/2016
TU Kältetechnik, Dresden	11/2016
Kopf SynGas, Sulz	11/2016
INTVEN, Bellevue (USA)	11/2016
DREWAG Dresden, Dresden	10/2016
AGO AG Energie+Anlagen, Kulmbach	10/2016
Universität Stuttgart, ITW, Stuttgart	09/2016
Pöry Deutschland GmbH, Dresden	09/2016
Siemens AG, Erlangen	09/2016
BASF über Fichtner IT Consulting AG	09/2016
B+B Engineering GmbH, Magdeburg	09/2016
Wilhelm Büchner Hochschule, Pfungstadt	08/2016

Webasto Thermo & Comfort SE, Gliching	08/2016
TU Dresden, Dresden	08/2016
Endress+Hauser Messtechnik GmbH+Co. KG, Hannover	08/2016
D + B Kältetechnik, Althausen	07/2016
Fichtner IT Consulting AG, Stuttgart	07/2016
AB Electrolux, Krakow, Poland	07/2016
ENEXIO Germany GmbH, Herne	07/2016
VPC GmbH, Vetschau/Spreewald	07/2016
INWAT, Lodz, Poland	07/2016
E.ON SE, Düsseldorf	07/2016
Planungsbüro Waidhas GmbH, Chemnitz	07/2016
EEB Enerko, Aldershoven	07/2016
IHEBA Naturenergie GmbH & Co. KG, Pfaffenhofen	07/2016
SSP Kälteplaner AG, Wolfertschwenden	07/2016
EEB ENERKO Energiewirtschaftliche Beratung GmbH, Berlin	07/2016
BOGE Kompressoren Otto BOGE GmbH & Co KG, Bielefeld	06/2016
Universidad Carlos III de Madrid, Madrid, Spain	04/2016
INWAT, Lodz, Poland	04/2016
Planungsbüro WAIDHAS GmbH, Chemnitz	04/2016
STEAG Energy Services GmbH, Laszlo Küppers, Zwingenberg	03/2016
WULFF & UMAG Energy Solutions GmbH, Husum	03/2016
FH Bielefeld, Bielefeld	03/2016
EWT Eckert Wassertechnik GmbH, Celle	03/2016
ILK Institut für Luft- und Kältetechnik GmbH, Dresden	02/2016, 06/2016
IEV KEMA - DNV GV – Energie, Dresden	02/2016
Allborg University, Department of Energie, Aalborg, Denmark	02/2016
G.A.M. Heat GmbH, Gräfenhainichen	02/2016
Institut für Luft- und Kältetechnik, Dresden	02/2016, 05/2016, 06/2016
Bosch, Stuttgart	02/2016
INL Idaho National Laboratory, Idaho, USA	11/2016, 01/2016
Friedl ID, Wien, Austria	01/2016
Technical University of Dresden, Dresden	01/2016

## 2015

EES Enerko, Aachen	12/2015
Ruldolf IB, Strau, Austria	12/2015
Allborg University, Department of Energie, Aalborg, Denmark	12/2015
University of Lyubljana, Slovenia	12/2015
Steinbrecht IB, Berlin	11/2015
Universidad Carlos III de Madrid, Madrid, Spain	11/2015
STEAK, Essen	11/2015
Bosch, Lohmar	10/2015
Team Turbo Machines, Rouen, France	09/2015
BTC – Business Technology Consulting AG, Oldenburg	07/2015
KIT Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen	07/2015
ILK, Dresden	07/2015
Schniewindt GmbH & Co. KG, Neuenwalde	08/2015

## 2014

PROJEKTPLAN, Dohna	04/2014
Technical University of Vienna, Austria	04/2014
MTU Aero Engines AG, Munich	04/2014
GKS, Schweinfurt	03/2014
Technical University of Nuremberg	03/2014
EP-E, Niederstetten	03/2014
Rückert NatUrgas GmbH, Lauf	03/2014
YESS-World, South Korea	03/2014
ZAB, Dessau	02/2014
KIT-TVT, Karlsruhe	02/2014
Stadtwerke Neuburg	02/2014
COMPAREX, Leipzig for RWE Essen	02/2014
Technical University of Prague, Czech Republic	02/2014
HS Augsburg	02/2014
Envi-con, Nuremberg	01/2014
DLR, Stuttgart	01/2014
Doosan Lentjes, Ratingen	01/2014
Technical University of Berlin	01/2014
Technical University of Munich	01/2014
Technical University of Braunschweig	01/2014
M&M Turbinentechnik, Bielefeld	01/2014

## 2013

TRANTER-GmbH, Artern	12/2013
SATAKE, Shanghai, China	12/2013
VOITH, Kunshan, China	12/2013
ULT, Löbau	12/2013
MAN, Copenhagen, Dänemark	11/2013
DREWAG, Dresden	11/2013
Haarslev Industries, Herlev, Dänemark	11/2013
STEAG, Herne	11/2013, 12/2013
Ingersoll-Rand, Oberhausen	11/2013
Wilhelm-Büchner HS, Darmstadt	10/2013
IAV, Chemnitz	10/2013
Technical University of Regensburg	10/2013
PD-Energy, Bitterfeld	09/2013
Thermofin, Heinsdorfergrund	09/2013
SHI, New Jersey, USA	09/2013
M&M Turbinentechnik, Bielefeld	08/2013
BEG-BHV, Bremerhaven	08/2013
TIG-Group, Husum	08/2013
COMPAREX, Leipzig for RWE Essen	08/2013, 11/2013 12/2013
University of Budapest, Hungary	08/2013
Siemens, Frankenthal	08/2013, 10/2013

		11/2013
VGB, Essen		07/2013, 11/2013
Brunner Energieberatung, Zurich, Switzerland		07/2013
Technical University of Deggendorf		07/2013
University of Maryland, USA		07/2013, 08/2013
University of Princeton, USA		07/2013
NIST, Boulder, USA		06/2013
IGUS GmbH, Dresden		06/2013
BHR Bilfinger, Essen		06/2013
SÜDSALZ, Bad Friedrichshall		06/2013, 12/2013
Technician School of Berlin		05/2013
KIER, Gajeong-ro, Südkorea		05/2013
Schwing/Stetter GmbH, Memmingen		05/2013
Vattenfall, Berlin		05/2013
AUTARK, Kleinmachnow		05/2013
STEAG, Zwingenberg		05/2013
Hochtief, Düsseldorf		05/2013
University of Stuttgart		04/2013
Technical University -Bundeswehr, Munich		04/2013
Rerum Cognitio Forschungszentrum, Frankfurt		04/2013
Kältetechnik Dresen + Bremen, Alfhausen		04/2013
University Auckland, New Zealand		04/2013
MASDAR Institut, Abu Dhabi, United Arab Emirates		03/2013
Simpelkamp, Dresden		02/2013
VEO, Eisenhüttenstadt		02/2013
ENTEC, Auerbach		02/2013
Caterpillar, Kiel		02/2013
Technical University of Wismar		02/2013
Technical University of Dusseldorf		02/2013
ILK, Dresden		01/2013, 08/2013
Fichtner IT, Stuttgart		01/2013, 11/2013
Schnepf Ingenierbüro, Nagold		01/2013
Schütz Engineering, Wadgassen		01/2013
Endress & Hauser, Reinach, Switzerland		01/2013
Oschatz GmbH, Essen		01/2013
frischli Milchwerke, Rehburg-Loccum		01/2013

## 2012

Voith, Bayreuth	12/2012
Technical University of Munich	12/2012
Dillinger Huette	12/2012
University of Stuttgart	11/2012
Siemens, Muehlheim	11/2012
Sennheiser, Hannover	11/2012
Oschatz GmbH, Essen	10/2012
Fichtner IT, Stuttgart	10/2012, 11/2012
Helbling Technik AG, Zurich, Switzerland	10/2012
University of Duisburg	10/2012

Rerum Cognitio Forschungszentrum, Frankfurt	09/2012
Pöyry Deutschland GmbH, Dresden	08/2012
Extracciones, Guatemala	08/2012
RWE, Essen	08/2012
Weghaus Consulting Engineers, Wuerzburg	08/2012
GKS, Schweinfurt	07/2012
COMPAREX, Leipzig for RWE Essen	07/2012
GEA, Nobitz	07/2012
Meyer Werft, Papenburg	07/2012
STEAG, Herne	07/2012
GRS, Cologne	06/2012
Fichtner IT Consult, Chennai, India	06/2012
Siemens, Freiburg	06/2012
Nikon Research of America, Belmont, USA	06/2012
Niederrhein University of Applied Sciences, Krefeld	06/2012
STEAG, Zwingenberg	06/2012
Mainova, Frankfurt on Main via Fichtner IT Consult	05/2012
Endress & Hauser	05/2012
PEU, Espenheim	05/2012
Luzern University of Applied Sciences, Switzerland	05/2012
BASF, Ludwigshafen (general license) via Fichtner IT Consult	05/2012
SPX Balcke-Dürr, Ratingen	05/2012, 07/2012
Gruber-Schmidt, Wien, Austria	04/2012
Vattenfall, Berlin	04/2012
ALSTOM, Baden	04/2012
SKW, Piesteritz	04/2012
TERA Ingegneria, Trento, Italy	04/2012
Siemens, Erlangen	04/2012, 05/2012
LAWI Power, Dresden	04/2012
Stadtwerke Leipzig	04/2012
SEITZ, Wetzikon, Switzerland	03/2012, 07/2012
M & M, Bielefeld	03/2012
Sennheiser, Wedemark	03/2012
SPG, Montreuil Cedex, France	02/2012
German Destilation, Sprendlingen	02/2012
Lopez, Munguia, Spain	02/2012
Endress & Hauser, Hannover	02/2012
Palo Alto Research Center, USA	02/2012
WIPAK, Walsrode	02/2012
Freudenberg, Weinheim	01/2012
Fichtner, Stuttgart	01/2012
airinotec, Bayreuth	01/2012, 07/2012
University Auckland, New Zealand	01/2012
VPC, Vetschau	01/2012
Franken Guss, Kitzingen	01/2012

## 2011

XRG-Simulation, Hamburg	12/2011
Smurfit Kappa PPT, AX Roermond, Netherlands	12/2011
AWTEC, Zurich, Switzerland	12/2011
eins-energie, Bad Elster	12/2011
BeNow, Rodenbach	11/2011
Luzern University of Applied Sciences, Switzerland	11/2011
GMVA, Oberhausen	11/2011
CCI, Karlsruhe	10/2011
W.-Büchner University of Applied Sciences, Pfungstadt	10/2011
PLANAIR, La Sagne, Switzerland	10/2011
LAWI, Dresden	10/2011
Lopez, Munguia, Spain	10/2011
University of KwaZulu-Natal, Westville, South Africa	10/2011
Voith, Heidenheim	09/2011
SpgBe Montreal, Canada	09/2011
SPG TECH, Montreuil Cedex, France	09/2011
Voith, Heidenheim-Mergelstetten	09/2011
MTU Aero Engines, Munich	08/2011
MIBRAG, Zeitz	08/2011
RWE, Essen	07/2011
Fels, Elingerode	07/2011
Weihenstephan University of Applied Sciences	07/2011, 09/2011
	10/2011
Forschungszentrum Juelich	07/2011
RWTH Aachen University	07/2011, 08/2011
INNEO Solutions, Ellwangen	06/2011
Caliqua, Basel, Switzerland	06/2011
Technical University of Freiberg	06/2011
Fichtner IT Consulting, Stuttgart	05/2011, 06/2011, 08/2011
	05/2011
Salzgitter Flachstahl, Salzgitter	05/2011
Helbling Beratung & Bauplanung, Zurich, Switzerland	05/2011
INEOS, Cologne	04/2011
Enseleit Consulting Engineers, Siebigerode	04/2011
Witt Consulting Engineers, Stade	03/2011
Helbling, Zurich, Switzerland	03/2011
MAN Diesel, Copenhagen, Denmark	03/2011
AGO, Kulmbach	03/2011
University of Duisburg	03/2011, 06/2011
CCP, Marburg	03/2011
BASF, Ludwigshafen	02/2011
ALSTOM Power, Baden, Switzerland	02/2011
Universität der Bundeswehr, Munich	02/2011
Calorifer, Elgg, Switzerland	01/2011
STRABAG, Vienna, Austria	01/2011
TUEV Sued, Munich	01/2011

ILK Dresden	01/2011
Technical University of Dresden	01/2011, 05/2011
	06/2011, 08/2011

## 2010

Umweltinstitut Neumarkt	12/2010
YIT Austria, Vienna, Austria	12/2010
MCI Innsbruck, Austria	12/2010
University of Stuttgart	12/2010
HS Cooler, Wittenburg	12/2010
Visteon, Novi Jicin, Czech Republic	12/2010
CompuWave, Brunntal	12/2010
Stadtwerke Leipzig	12/2010
MCI Innsbruck, Austria	12/2010
EVONIK Energy Services, Zwingenberg	12/2010
Caliqua, Basel, Switzerland	11/2010
Shanghai New Energy Resources Science & Technology, China	11/2010
Energieversorgung Halle	11/2010
Hochschule für Technik Stuttgart, University of Applied Sciences	11/2010
Steinmueller, Berlin	11/2010
Amberg-Weiden University of Applied Sciences	11/2010
AREVA NP, Erlangen	10/2010
MAN Diesel, Augsburg	10/2010
KRONES, Neutraubling	10/2010
Vaillant, Remscheid	10/2010
PC Ware, Leipzig	10/2010
Schubert Consulting Engineers, Weißenberg	10/2010
Fraunhofer Institut UMSICHT, Oberhausen	10/2010
Behringer Consulting Engineers, Tagmersheim	09/2010
Saacke, Bremen	09/2010
WEBASTO, Neubrandenburg	09/2010
Concordia University, Montreal, Canada	09/2010
Compañía Eléctrica de Sochagota, Bogota, Colombia	08/2010
Hannover University of Applied Sciences	08/2010
ERGION, Mannheim	07/2010
Fichtner IT Consulting, Stuttgart	07/2010
TF Design, Matieland, South Africa	07/2010
MCE, Berlin	07/2010, 12/2010
IPM, Zittau/Goerlitz University of Applied Sciences	06/2010
TUEV Sued, Dresden	06/2010
RWE IT, Essen	06/2010
Glen Dimplex, Kulmbach	05/2010, 07/2010 10/2010
Hot Rock, Karlsruhe	05/2010
Darmstadt University of Applied Sciences	05/2010
Voith, Heidenheim	04/2010
CombTec, Zittau	04/2010
University of Glasgow, Great Britain	04/2010

Universitaet der Bundeswehr, Munich	04/2010
Technical University of Hamburg-Harburg	04/2010
Vattenfall Europe, Berlin	04/2010
HUBER Consulting Engineers, Berching	04/2010
VER, Dresden	04/2010
CCP, Marburg	03/2010
Offenburg University of Applied Sciences	03/2010
Technical University of Berlin	03/2010
NIST Boulder CO, USA	03/2010
Technical University of Dresden	02/2010
Siemens Energy, Nuremberg	02/2010
Augsburg University of Applied Sciences	02/2010
ALSTOM Power, Baden, Switzerland	02/2010, 05/2010
MIT Massachusetts Institute of Technology Cambridge MA, USA	02/2010
Wieland Werke, Ulm	01/2010
Siemens Energy, Goerlitz	01/2010, 12/2010
Technical University of Freiberg	01/2010
ILK, Dresden	01/2010, 12/2010
Fischer-Uhrig Consulting Engineers, Berlin	01/2010

## 2009

ALSTOM Power, Baden, Schweiz	01/2009, 03/2009 05/2009
Nordostschweizerische Kraftwerke AG, Doettingen, Switzerland	02/2009
RWE, Neurath	02/2009
Brandenburg University of Technology, Cottbus	02/2009
Hamburg University of Applied Sciences	02/2009
Kehrein, Moers	03/2009
EPP Software, Marburg	03/2009
Bernd Münstermann, Telgte	03/2009
Suedzucker, Zeitz	03/2009
CPP, Marburg	03/2009
Gelsenkirchen University of Applied Sciences	04/2009
Regensburg University of Applied Sciences	05/2009
Gatley & Associates, Atlanta, USA	05/2009
BOSCH, Stuttgart	06/2009, 07/2009
Dr. Nickolay, Consulting Engineers, Gommersheim	06/2009
Ferrostal Power, Saarlouis	06/2009
BHR Bilfinger, Essen	06/2009
Intraserv, Wiesbaden	06/2009
Lausitz University of Applied Sciences, Senftenberg	06/2009
Nuernberg University of Applied Sciences	06/2009
Technical University of Berlin	06/2009
Fraunhofer Institut UMSICHT, Oberhausen	07/2009
Bischoff, Aurich	07/2009
Fichtner IT Consulting, Stuttgart	07/2009
Techsoft, Linz, Austria	08/2009
DLR, Stuttgart	08/2009

Wienstrom, Vienna, Austria	08/2009
RWTH Aachen University	09/2009
Vattenfall, Hamburg	10/2009
AIC, Chemnitz	10/2009
Midiplan, Bietigheim-Bissingen	11/2009
Institute of Air Handling and Refrigeration ILK, Dresden	11/2009
FZD, Rossendorf	11/2009
Techgroup, Ratingen	11/2009
Robert Sack, Heidelberg	11/2009
EC, Heidelberg	11/2009
MCI, Innsbruck, Austria	12/2009
Saacke, Bremen	12/2009
ENERKO, Aldenhoven	12/2009

## 2008

Pink, Langenwang	01/2008
Fischer-Uhrig, Berlin	01/2008
University of Karlsruhe	01/2008
MAAG, Kuesnacht, Switzerland	02/2008
M&M Turbine Technology, Bielefeld	02/2008
Lentjes, Ratingen	03/2008
Siemens Power Generation, Goerlitz	04/2008
Evonik, Zwingenberg (general EBSILON program license)	04/2008
WEBASTO, Neubrandenburg	04/2008
CFC Solutions, Munich	04/2008
RWE IT, Essen	04/2008
Rerum Cognitio, Zwickau	04/2008, 05/2008
ARUP, Berlin	05/2008
Research Center, Karlsruhe	07/2008
AWECO, Neukirch	07/2008
Technical University of Dresden, Professorship of Building Services	07/2008
Technical University of Cottbus, Chair in Power Plant Engineering	07/2008, 10/2008
Ingersoll-Rand, Unicov, Czech Republic	08/2008
Technip Benelux BV, Zoetermeer, Netherlands	08/2008
Fennovoima Oy, Helsinki, Finland	08/2008
Fichtner Consulting & IT, Stuttgart	09/2008
PEU, Espenhain	09/2008
Popty, Dresden	09/2008
WINGAS, Kassel	09/2008
TUEV Sued, Dresden	10/2008
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	10/2008, 11/2008
AWTEC, Zurich, Switzerland	11/2008
Siemens Power Generation, Erlangen	12/2008

## 2007

Audi, Ingolstadt	02/2007
ANO Abfallbehandlung Nord, Bremen	02/2007
TUEV NORD SysTec, Hamburg	02/2007
VER, Dresden	02/2007
Technical University of Dresden, Chair in Jet Propulsion Systems	02/2007
Redacom, Nidau, Switzerland	02/2007
Universität der Bundeswehr, Munich	02/2007
Maxxtec, Sinsheim	03/2007
University of Rostock, Chair in Technical Thermodynamics	03/2007
AGO, Kulmbach	03/2007
University of Stuttgart, Chair in Aviation Propulsions	03/2007
Siemens Power Generation, Duisburg	03/2007
ENTHAL Haustechnik, Rees	05/2007
AWECO, Neukirch	05/2007
ALSTOM, Rugby, Great Britain	06/2007
SAAS, Possendorf	06/2007
Grenzebach BSH, Bad Hersfeld	06/2007
Reichel Engineering, Haan	06/2007
Technical University of Cottbus, Chair in Power Plant Engineering	06/2007
Voith Paper Air Systems, Bayreuth	06/2007
Egger Holzwerkstoffe, Wismar	06/2007
Tissue Europe Technologie, Mannheim	06/2007
Dometic, Siegen	07/2007
RWTH Aachen University, Institute for Electrophysics	09/2007
National Energy Technology Laboratory, Pittsburg, USA	10/2007
Energieversorgung Halle	10/2007
AL-KO, Jettingen	10/2007
Grenzebach BSH, Bad Hersfeld	10/2007
Wiesbaden University of Applied Sciences, Department of Engineering Sciences	10/2007
Endress+Hauser Messtechnik, Hannover	11/2007
Munich University of Applied Sciences, Department of Mechanical Engineering	11/2007
Rerum Cognitio, Zwickau	12/2007
Siemens Power Generation, Erlangen	11/2007
University of Rostock, Chair in Technical Thermodynamics	11/2007, 12/2007

## 2006

STORA ENSO Sachsen, Eilenburg	01/2006
Technical University of Munich, Chair in Energy Systems	01/2006
NUTEC Engineering, Bisikon, Switzerland	01/2006, 04/2006
Conwel eco, Bochov, Czech Republic	01/2006
Offenburg University of Applied Sciences	01/2006
KOCH Transporttechnik, Wadgassen	01/2006
BEG Bremerhavener Entsorgungsgesellschaft	02/2006
Deggendorf University of Applied Sciences, Department of Mechanical Engineering and Mechatronics	02/2006
University of Stuttgart,	02/2006

Department of Thermal Fluid Flow Engines	
Technical University of Munich,	02/2006
Chair in Apparatus and Plant Engineering	
Energietechnik Leipzig (company license),	02/2006
Siemens Power Generation, Erlangen	02/2006, 03/2006
RWE Power, Essen	03/2006
WAETAS, Pobershau	04/2006
Siemens Power Generation, Goerlitz	04/2006
Technical University of Braunschweig,	04/2006
Department of Thermodynamics	
EnviCon & Plant Engineering, Nuremberg	04/2006
Brassel Engineering, Dresden	05/2006
University of Halle-Merseburg,	05/2006
Department of USET Merseburg incorporated society	
Technical University of Dresden,	05/2006
Professorship of Thermic Energy Machines and Plants	
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	05/2006
Suedzucker, Ochsenfurt	06/2006
M&M Turbine Technology, Bielefeld	06/2006
Feistel Engineering, Volkach	07/2006
ThyssenKrupp Marine Systems, Kiel	07/2006
Caliqua, Basel, Switzerland (company license)	09/2006
Atlas-Stord, Rodovre, Denmark	09/2006
Konstanz University of Applied Sciences, Course of Studies Construction and Development	10/2006
Siemens Power Generation, Duisburg	10/2006
Hannover University of Applied Sciences, Department of Mechanical Engineering	10/2006
Siemens Power Generation, Berlin	11/2006
Zikesch Armaturentechnik, Essen	11/2006
Wismar University of Applied Sciences, Seafaring Department	11/2006
BASF, Schwarzeide	12/2006
Enertech Energie und Technik, Radebeul	12/2006

## 2005

TUEV Nord, Hannover	01/2005
J.H.K Plant Engineering and Service, Bremerhaven	01/2005
Electrowatt-EKONO, Zurich, Switzerland	01/2005
FCIT, Stuttgart	01/2005
Energietechnik Leipzig (company license)	02/2005, 04/2005
	07/2005
eta Energieberatung, Pfaffenhofen	02/2005
FZR Forschungszentrum, Rossendorf/Dresden	04/2005
University of Saarbruecken	04/2005
Technical University of Dresden	04/2005
Professorship of Thermic Energy Machines and Plants	
Grenzebach BSH, Bad Hersfeld	04/2005
TUEV Nord, Hamburg	04/2005

Technical University of Dresden, Waste Management	05/2005
Siemens Power Generation, Goerlitz	05/2005
Duesseldorf University of Applied Sciences,	05/2005
Department of Mechanical Engineering and Process Engineering	
Redacom, Nidau, Switzerland	06/2005
Dumas Verfahrenstechnik, Hofheim	06/2005
Alensys Engineering, Erkner	07/2005
Stadtwerke Leipzig	07/2005
SaarEnergie, Saarbruecken	07/2005
ALSTOM ITC, Rugby, Great Britain	08/2005
Technical University of Cottbus, Chair in Power Plant Engineering	08/2005
Vattenfall Europe, Berlin (group license)	08/2005
Technical University of Berlin	10/2005
Basel University of Applied Sciences,	10/2005
Department of Mechanical Engineering, Switzerland	
Midiplan, Bietigheim-Bissingen	11/2005
Technical University of Freiberg, Chair in Hydrogeology	11/2005
STORA ENSO Sachsen, Eilenburg	12/2005
Energieversorgung Halle (company license)	12/2005
KEMA IEV, Dresden	12/2005

## 2004

Vattenfall Europe (group license)	01/2004
TUEV Nord, Hamburg	01/2004
University of Stuttgart, Institute of Thermodynamics and Heat Engineering	02/2004
MAN B&W Diesel A/S, Copenhagen, Denmark	02/2004
Siemens AG Power Generation, Erlangen	02/2004
Ulm University of Applied Sciences	03/2004
Visteon, Kerpen	03/2004, 10/2004
Technical University of Dresden,	
Professorship of Thermic Energy Machines and Plants	04/2004
Rerum Cognitio, Zwickau	04/2004
University of Saarbruecken	04/2004
Grenzebach BSH, Bad Hersfeld	04/2004
SOFBID Zwingenberg (general EBSILON program license)	04/2004
EnBW Energy Solutions, Stuttgart	05/2004
HEW-Kraftwerk, Tiefstack	06/2004
h s energieanlagen, Freising	07/2004
FCIT, Stuttgart	08/2004
Physikalisch Technische Bundesanstalt (PTB), Braunschweig	08/2004
Mainova Frankfurt	08/2004
Rietschle Energieplaner, Winterthur, Switzerland	08/2004
MAN Turbo Machines, Oberhausen	09/2004
TUEV Sued, Dresden	10/2004
STEAG Kraftwerk, Herne	10/2004, 12/2004
University of Weimar	10/2004
energeticals (e-concept), Munich	11/2004
SorTech, Halle	11/2004

Enertech EUT, Radebeul (company license)	11/2004
Munich University of Applied Sciences	12/2004
STORA ENSO Sachsen, Eilenburg	12/2004
Technical University of Cottbus, Chair in Power Plant Engineering	12/2004
Freudenberg Service, Weinheim	12/2004

## 2003

Paper Factory, Utzenstorf, Switzerland	01/2003
MAB Plant Engineering, Vienna, Austria	01/2003
Wulff Energy Systems, Husum	01/2003
Technip Benelux BV, Zoetermeer, Netherlands	01/2003
ALSTOM Power, Baden, Switzerland	01/2003, 07/2003
VER, Dresden	02/2003
Rietschle Energieplaner, Winterthur, Switzerland	02/2003
DLR, Leupholdhausen	04/2003
Emden University of Applied Sciences, Department of Technology	05/2003
Pettersson+Ahrends, Ober-Moerlen	05/2003
SOFBID ,Zwingenberg (general EBSILON program license)	05/2003
Ingenieurbuero Ostendorf, Gummersbach	05/2003
TUEV Nord, Hamburg	06/2003
Muenstermann GmbH, Telgte-Westbevern	06/2003
University of Cali, Colombia	07/2003
Atlas-Stord, Rodovre, Denmark	08/2003
ENERKO, Aldenhoven	08/2003
STEAG RKB, Leuna	08/2003
eta Energieberatung, Pfaffenhofen	08/2003
exergie, Dresden	09/2003
AWTEC, Zurich, Switzerland	09/2003
Energie, Timelkam, Austria	09/2003
Electrowatt-EKONO, Zurich, Switzerland	09/2003
LG, Annaberg-Buchholz	10/2003
FZR Forschungszentrum, Rossendorf/Dresden	10/2003
EnviCon & Plant Engineering, Nuremberg	11/2003
Visteon, Kerpen	11/2003
VEO Vulkan Energiewirtschaft Oderbruecke, Eisenhuettenstadt	11/2003
Stadtwerke Hannover	11/2003
SaarEnergie, Saarbruecken	11/2003
Fraunhofer-Gesellschaft, Munich	12/2003
Erfurt University of Applied Sciences, Department of Supply Engineering	12/2003
SorTech, Freiburg	12/2003
Mainova, Frankfurt	12/2003
Energieversorgung Halle	12/2003

## 2002

Hamilton Medical AG, Rhaeuens, Switzerland	01/2002
Bochum University of Applied Sciences, Department of Thermo- and Fluid Dynamics	01/2002

SAAS, Possendorf/Dresden	02/2002
Siemens, Karlsruhe	02/2002
(general license for the WinIS information system)	
FZR Forschungszentrum, Rossendorf/Dresden	03/2002
CompAir, Simmern	03/2002
GKS Gemeinschaftskraftwerk, Schweinfurt	04/2002
ALSTOM Power Baden, Switzerland (group licenses)	05/2002
InfraServ, Gendorf	05/2002
SoftSolutions, Muehlhausen (company license)	05/2002
DREWAG, Dresden (company license)	05/2002
SOFBID, Zwingenberg	06/2002
(general EBSILON program license)	
Kleemann Engineering, Dresden	06/2002
Caliqua, Basel, Switzerland (company license)	07/2002
PCK Raffinerie, Schwedt (group license)	07/2002
Fischer-Uhrig Engineering, Berlin	08/2002
Fichtner Consulting & IT, Stuttgart	08/2002
(company licenses and distribution)	
Stadtwerke Duisburg	08/2002
Stadtwerke Hannover	09/2002
Siemens Power Generation, Goerlitz	10/2002
Energieversorgung Halle (company license)	10/2002
Bayer, Leverkusen	11/2002
Dillinger Huette, Dillingen	11/2002
G.U.N.T. Geraetebau, Barsbuettel	12/2002
(general license and training test benches)	
VEAG, Berlin (group license)	12/2002

## 2001

ALSTOM Power, Baden, Switzerland	01/2001, 06/2001 12/2001
KW2 B. V., Amersfoot, Netherlands	01/2001, 11/2001
Eco Design, Saitamaken, Japan	01/2001
M&M Turbine Technology, Bielefeld	01/2001, 09/2001
MVV Energie, Mannheim	02/2001
Technical University of Dresden, Department of Power Machinery and Plants	02/2001
PREUSSAG NOELL, Wuerzburg	03/2001
Fichtner Consulting & IT Stuttgart	04/2001
(company licenses and distribution)	
Muenstermann GmbH, Telgte-Westbevern	05/2001
SaarEnergie, Saarbruecken	05/2001
Siemens, Karlsruhe	08/2001
(general license for the WinIS information system)	
Neusiedler AG, Ulmerfeld, Austria	09/2001
h s energieanlagen, Freising	09/2001
Electrowatt-EKONO, Zurich, Switzerland	09/2001
IPM Zittau/Goerlitz University of Applied Sciences (general license)	10/2001

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

## 2000

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

## 1999

Bayernwerk, Munich	01/1999
DREWAG, Dresden (company license)	02/1999
KEMA IEV, Dresden	03/1999
Regensburg University of Applied Sciences	04/1999
Fichtner Consulting & IT, Stuttgart	07/1999
(company licenses and distribution)	
Technical University of Cottbus, Chair in Power Plant Engineering	07/1999
Technical University of Graz, Department of Thermal Engineering, Austria	11/1999
Ostendorf Engineering, Gummersbach	12/1999

## 1998

Technical University of Cottbus, Chair in Power Plant Engineering	05/1998
Fichtner Consulting & IT (CADIS information systems) Stuttgart	05/1998
(general KPRO program license)	
M&M Turbine Technology Bielefeld	06/1998
B+H Software Engineering Stuttgart	08/1998
Alfa Engineering, Switzerland	09/1998
VEAG Berlin (group license)	09/1998
NUTEC Engineering, Bisikon, Switzerland	10/1998

SCA Hygiene Products, Munich	10/1998
RWE Energie, Neurath	10/1998
Wilhelmshaven University of Applied Sciences	10/1998
BASF, Ludwigshafen (group license)	11/1998
Energieversorgung, Offenbach	11/1998

## 1997

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