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

**FluidEXL *Graphics***  
with **LibIdGasMix**  
for Excel<sup>®</sup>

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

## LibIdGasMix FluidEXL<sup>Graphics</sup> English

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## 0. Package Contents

### 0.1 Zip files for 32-bit Windows®

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

**Zip-file "CD\_FluidEXL\_Graphics\_LibIdGasMix\_Eng.zip" including the following files:**

|                                            |                                                                                          |
|--------------------------------------------|------------------------------------------------------------------------------------------|
| FluidEXL_Graphics_Eng_Setup.exe            | - English installation program for the FluidEXL <i>Graphics</i> Add-In for use in Excel® |
| FluidEXL_Graphics_Eng.xla                  | - English Add-In FluidEXL <i>Graphics</i> for Excel                                      |
| LibIdGasMix.dll                            | - DLL with functions for ideal gases and gas mixtures                                    |
| LibIdGasMix.hlp                            | - Help file for the LibIdGasMix property library                                         |
| FluidEXL_Graphics_LibIdGasMix_Docu_Eng.pdf | - User's Guide                                                                           |

**Zip-file "CD\_FluidEXL\_Graphics\_LibIdGasMix.zip" including the following files:**

|                                            |                                                                                                  |
|--------------------------------------------|--------------------------------------------------------------------------------------------------|
| FluidEXL_Graphics_Setup.exe                | - German installation program for the Add-In FluidEXL <i>Graphics</i> for application in Excel®. |
| FluidEXL_Graphics.xla                      | - German Add-In for FluidEXL <i>Graphics</i>                                                     |
| LibIdGasMix.dll                            | - DLL with functions for ideal gases and gas mixtures                                            |
| LibIdGasMix.hlp                            | - Help file for the LibIdGasMix property library                                                 |
| FluidEXL_Graphics_LibIdGasMix_Docu_Eng.pdf | - User's Guide                                                                                   |

### 0.2 Zip files for 64-bit Windows®

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

**Zip-file "CD\_FluidEXL\_Graphics\_LibIdGasMix\_x64\_Eng.zip" including the following files and folders:**

#### Files:

|                                            |                                                                        |
|--------------------------------------------|------------------------------------------------------------------------|
| FluidEXL_Graphics_LibIdGasMix_Docu_Eng.pdf | - User's Guide                                                         |
| FluidEXL_Graphics_Eng.xla                  | - FluidEXL <i>Graphics</i> Add-In                                      |
| FluidEXL_Graphics_Eng_64_Setup.msi         | - Self-extracting and self-installing program                          |
| LibIdGasMix.dll                            | - Dynamic link library with functions for ideal gases and gas mixtures |
| LibIdGasMix.hlp                            | - Help file for the LibIdGasMix property library                       |

|           |                                                                                |
|-----------|--------------------------------------------------------------------------------|
| Setup.exe | - Self-extracting and self-installing program for FluidEXL <sup>Graphics</sup> |
|-----------|--------------------------------------------------------------------------------|

**Folders:**

|              |                                                                              |
|--------------|------------------------------------------------------------------------------|
| vcredist_x64 | - Folder containing the "Microsoft Visual C++ 2010 x64 Redistributable Pack" |
|--------------|------------------------------------------------------------------------------|

|                     |                                                       |
|---------------------|-------------------------------------------------------|
| WindowsInstaller3_1 | - Folder containing the "Microsoft Windows Installer" |
|---------------------|-------------------------------------------------------|

**German zip file "CD\_FluidEXL\_Graphics\_LibCO2\_x64.zip" including the following files and folders:**

**Files:**

|                                            |                                                                                |
|--------------------------------------------|--------------------------------------------------------------------------------|
| FluidEXL_Graphics_LibIdGasMix_Docu_Eng.pdf | - User's Guide                                                                 |
| FluidEXL_Graphics.xla                      | - German FluidEXL <sup>Graphics</sup> Add-In                                   |
| FluidEXL_Graphics_64_Setup.msi             | - Self-extracting and self-installing program                                  |
| LibIdGasMix.dll                            | - Dynamic link library with functions for ideal gases and gas mixtures         |
| LibIdGasMix.hlp                            | - Help file for the LibIdGasMix property library                               |
| Setup.exe                                  | - Self-extracting and self-installing program for FluidEXL <sup>Graphics</sup> |

**Folders:**

|              |                                                                              |
|--------------|------------------------------------------------------------------------------|
| vcredist_x64 | - Folder containing the "Microsoft Visual C++ 2010 x64 Redistributable Pack" |
|--------------|------------------------------------------------------------------------------|

|                     |                                                       |
|---------------------|-------------------------------------------------------|
| WindowsInstaller3_1 | - Folder containing the "Microsoft Windows Installer" |
|---------------------|-------------------------------------------------------|

# 1. Property Functions

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

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

| Property function                                                                      | Function Name      | Call from Fortran                                                              | Property or function                                                        | Unit of the value calculated | Details |
|----------------------------------------------------------------------------------------|--------------------|--------------------------------------------------------------------------------|-----------------------------------------------------------------------------|------------------------------|---------|
| $p = f(p, t, \text{type}, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$    | p_ts_igmix         | P_TS_IGMIX(T,S,TYPE,COMP(0:30))<br>C_P_TS_IGMIX(P,T,S,TYPE,COMP(0:30))         | Backward function:<br>Mixture pressure from temperature and entropy         | bar                          | 3/10    |
| $p = f(t, v, \text{type}, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$    | p_tv_igmix         | P_TV_IGMIX(T,V,TYPE,COMP(0:30))<br>C_P_TV_IGMIX(P,T,V,TYPE,COMP(0:30))         | Backward function:<br>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))<br>C_PR_PT_IGMIX(PR,P,T,TYPE,COMP(0:30))      | Prandtl number of the mixture                                               |                              | 3/12    |
| $\psi_1 = f(\text{igas}, \xi_1 \dots \xi_{30})$                                        | psi_igas_xsi_igmix | PSI_IGAS_XSI_IGMIX(IGAS,XSI(0:30))<br>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))<br>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))<br>C_RHO_PT_IGMIX(RHO,P,T,COMP(0:30))             | Density of the mixture                                                      | kg/m <sup>3</sup>            | 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))<br>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))<br>C_T_PH_IGMIX(T,P,H,TYPE,COMP(0:30))         | Backward function:<br>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))<br>C_T_PS_IGMIX(T,P,S,TYPE,COMP(0:30))         | Backward function:<br>Temperature from mixture pressure and entropy         | °C                           | 3/18    |

| Property function                                                                   | Function Name      | Call from Fortran                                                              | Property or function                                                        | Unit of the value calculated | Details |
|-------------------------------------------------------------------------------------|--------------------|--------------------------------------------------------------------------------|-----------------------------------------------------------------------------|------------------------------|---------|
| $t = f(p, v, \text{type}, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$ | t_pv_igmix         | T_PV_IGMIX(P,V, IGAS)<br>C_T_PV_IGMIX(T,P,V, IGAS)                             | Backward function:<br>Temperature from mixture pressure and specific volume | °C                           | 3/19    |
| $u = f(p, t, \text{type}, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$ | u_pt_igmix         | U_PT_IGMIX(P,T, IGAS)<br>C_U_PT_IGMIX(U,P,T, IGAS)                             | Internal energy of the mixture                                              | kJ/kg                        | 3/20    |
| $v = f(p, t, \text{type}, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})$ | v_pt_igmix         | V_PT_IGMIX(P,T,TYPE,COMP(0:30))<br>C_V_PT_IGMIX(V,P,T,TYPE,COMP(0:30))         | Specific volume of the mixture                                              | m³/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))<br>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))<br>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:<br>type = 1 for the composition as mass fractions $\xi_1, \dots, \xi_{30}$<br>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 LibIdGasMix DLL:

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

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

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

| Property function             | Function Name | Call from Fortran                                     | Property or function                                                                | Unit of the value calculated | Details |
|-------------------------------|---------------|-------------------------------------------------------|-------------------------------------------------------------------------------------|------------------------------|---------|
| $p = f(t, v, \text{igas})$    | p_tv_igas     | P_TV_IGAS(T,V, IGAS)<br>C_P_TV_IGAS(P,T,V, IGAS)      | Backward function:<br>Pressure from temperature and specific volume of the gas igas | bar                          | 4/11    |
| $Pr = f(p, t, \text{igas})$   | Pr_pt_igas    | PR_PT_IGAS(P,T, IGAS)<br>C_PR_PT_IGAS(PR,P,T, IGAS)   | Prandtl number of the gas igas                                                      |                              | 4/12    |
| $R = f(\text{igas})$          | R_igas        | R_IGAS(IGAS)<br>C_R_IGAS(R,IGAS)                      | Specific gas constant of the gas igas                                               | kJ/(kg K)                    | 4/13    |
| $\rho = f(p, t, \text{igas})$ | rho_pt_igas   | RHO_PT_IGAS(P,T, IGAS)<br>C_RHO_PT_IGAS(RHO,P,T IGAS) | Density of the gas igas                                                             | kg/m <sup>3</sup>            | 4/14    |
| $s = f(p, t, \text{igas})$    | s_pt_igas     | S_PT_IGAS(P,T, IGAS)<br>C_S_PT_IGAS(S,P,T, IGAS)      | Entropy of the gas igas                                                             | kJ/(kg K)                    | 4/15    |
| $t = f(p, h, \text{igas})$    | t_ph_igas     | T_PH_IGAS(P,H, IGAS)<br>C_T_PH_IGAS(T,P,H IGAS)       | Backward function:<br>Temperature from pressure and enthalpy of the gas igas        | °C                           | 4/16    |
| $t = f(p, s, \text{igas})$    | t_ps_igas     | T_PS_IGAS(P,S, IGAS)<br>C_T_PS_IGAS(T,P,S, IGAS)      | Backward function:<br>Temperature from pressure and entropy of the gas igas         | °C                           | 4/17    |
| $t = f(p, v, \text{igas})$    | t_pv_igas     | T_PV_IGAS(P,V, IGAS)<br>C_T_PV_IGAS(T,P,V, IGAS)      | Backward function:<br>Temperature from pressure and specific volume of the gas igas | °C                           | 4/18    |
| $u = f(p, t, \text{igas})$    | u_pt_igas     | U_PT_IGAS(P,T, IGAS)<br>C_U_PT_IGAS(U,P,T, IGAS)      | Specific internal energy of the gas igas                                            | kJ/kg                        | 4/19    |
| $v = f(p, t, \text{igas})$    | v_pt_igas     | V_PT_IGAS(P,T, IGAS)<br>C_V_PT_IGAS(V,P,T, IGAS)      | Specific volume of the gas igas                                                     | m <sup>3</sup> /kg           | 4/20    |
| $w = f(p, t, \text{igas})$    | w_pt_igas     | W_PT_IGAS_SI(P,T IGAS)<br>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 |

### 1.3 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  $t = -73.15\text{ °C}$  to  $3026.85\text{ °C}$ .

Exceptions are:

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

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  $0.01\text{ bar}$  to  $10\text{ (30) bar}$ , maximum  $50\text{ bar}$ .

For temperatures above  $1000\text{ °C}$  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  $500\text{ °C}$ .

**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.*

**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]                                 |

1) 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 |

2) 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                                                      |

### 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  $i = \text{igas}$  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  $\text{H}_2\text{O}$  and  $\text{CO}_2$ .

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 triple states.

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

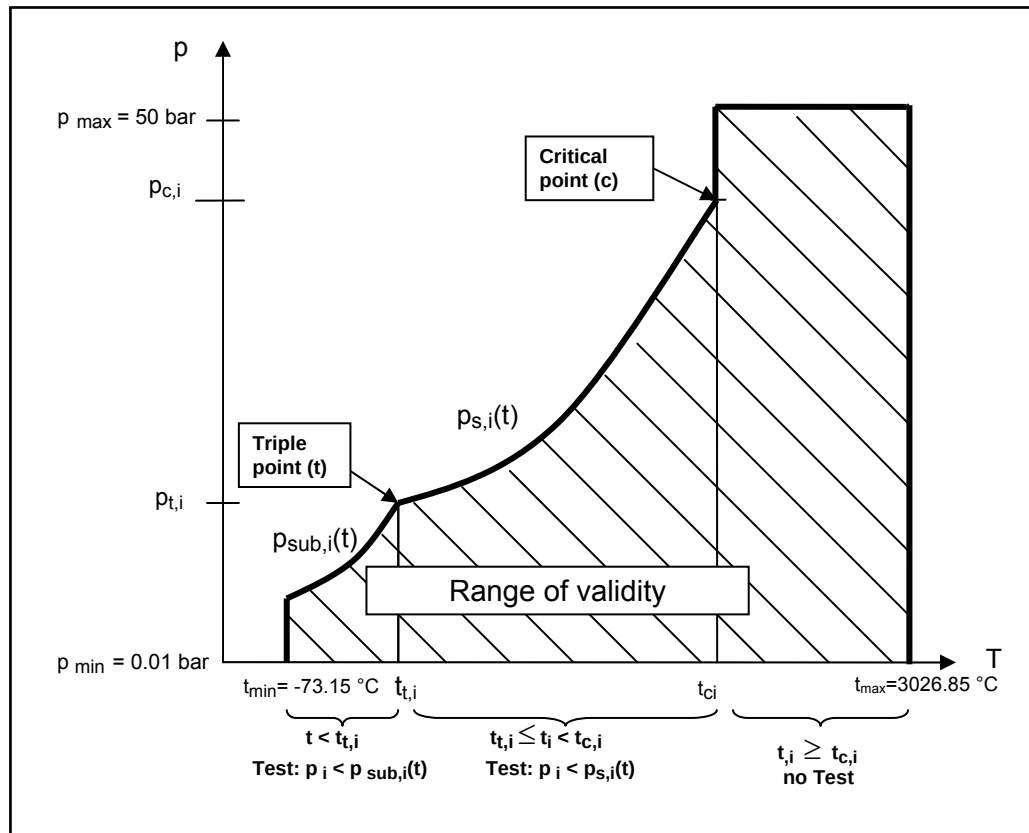


**Figure 1.** p-t diagram with the range of validity of a gas  $i = \text{igas}$  of the LibIdGasMix property library.

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

|           |                                    |                        | Critical point           |                         |           | Triple state             |                          |                       |
|-----------|------------------------------------|------------------------|--------------------------|-------------------------|-----------|--------------------------|--------------------------|-----------------------|
| Gas No. i | Mixture gas                        |                        | $p_{c,i}$ in bar[Source] | $t_{c,i}$ in °C[Source] | $p_s(t)$  | $p_{t,i}$ in bar[Source] | $t_{t,i}$ in °C [Source] | $p_{sub}(t)$ [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 FluidEXL<sup>Graphics</sup> in Excel<sup>®</sup>

The Add-In FluidEXL<sup>Graphics</sup> has been developed to calculate thermophysical properties in Excel<sup>®</sup> more conveniently. Within Excel, it enables the direct call of functions relating to ideal gases and gas mixtures from the LibIdGasMix property library.

### 2.1 Installing FluidEXL<sup>Graphics</sup>

If FluidEXL<sup>Graphics</sup> has not yet been installed or if there is a version installed which has been delivered before April 2010, please complete the initial installation procedure described below.

If FluidEXL<sup>Graphics</sup> has already been installed in a version which has been delivered after April 2010, you simply need to copy the files which belong to the LibIdGasMix library. In this case, follow the subsection "Adding the LibIdGasMix Library" on page 2/10.

#### Installing FluidEXL<sup>Graphics</sup> for 32-bit Windows<sup>®</sup>

Complete the following steps for initial installation of FluidEXL<sup>Graphics</sup>.

Before you begin, it is best to uninstall any trial version or full version of FluidEXL<sup>Graphics</sup> delivered before June 2010.

After you have downloaded and extracted the zip file

"CD\_FluidEXL\_Graphics\_LibIdGasMix\_Eng.zip" (for English version of Windows)

"CD\_FluidEXL\_Graphics\_LibIdGasMix.zip" (for German version of Windows)

you will see the folder

CD\_FluidEXL\_Graphics\_LibIdGasMix\_Eng (for English version of Windows)

CD\_FluidEXL\_Graphics\_LibIdGasMix (for German version of Windows)

in your Windows Explorer, Norton Commander etc.

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

Within this folder you will see the following files:

FluidEXL\_Graphics\_Eng\_Setup.exe (for English version of Windows)

FluidEXL\_Graphics\_Setup.exe (for German version of Windows)

FluidEXL\_Graphics\_Eng.xla (for English version of Windows)

FluidEXL\_Graphics.xla (for German version of Windows)

LibIdGasMix.dll

LibIdGasMix.hlp.

In order to run the installation of FluidEXL<sup>Graphics</sup> double-click the file

FluidEXL\_Graphics\_Eng\_Setup.exe (for English version of Windows)

FluidEXL\_Graphics\_Setup.exe (for German version of Windows).

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

In the following dialog box, "Choose Destination Location", the default path offered automatically for the installation of FluidEXL<sup>Graphics</sup> is

C:\Program Files\FuildEXL\_Graphics\_Eng (for English version of Windows)

C:\Programme\FuildEXL\_Graphics (for German version of Windows).

By clicking the "Browse..." button, you can change the installation directory before installation (see figure below).



**Figure 2.1:** Choose Destination Location

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

After FluidEXL *Graphics* has been installed, the sentence "FluidEXL Graphics English has been successfully installed." will be shown. Confirm this by clicking the "Finish" button.

During the installation process the following files

|                           |             |
|---------------------------|-------------|
| Advapi32.dll              | LC.dll      |
| DFORMD.dll                | Msvcp60.dll |
| Dforrt.dll                | Msvcrt.dll  |
| FluidEXL_Graphics_Eng.xla | UNWISE.EXE  |
| INSTALL_EXL.LOG           | UNWISE.INI  |

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

|                                        |                                  |
|----------------------------------------|----------------------------------|
| C:\Program Files\FuildEXL_Graphics_Eng | (for English version of Windows) |
| C:\Programme\FuildEXL_Graphics         | (for German version of Windows). |

In addition, the two subdirectories \FORMULATION97 and \FLuft have been compiled in the destination folder.

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

|                                      |                                  |
|--------------------------------------|----------------------------------|
| CD_FluidEXL_Graphics_LibIdGasMix_Eng | (for English version of Windows) |
| CD_FluidEXL_Graphics_LibIdGasMix     | (for German version of Windows)  |

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

|                                        |                                  |
|----------------------------------------|----------------------------------|
| C:\Program Files\FuildEXL_Graphics_Eng | (for English version of Windows) |
| C:\Programme\FuildEXL_Graphics         | (for German version of Windows). |

using an appropriate program such as Explorer or Norton Commander:

|                           |                                  |
|---------------------------|----------------------------------|
| FluidEXL_Graphics_Eng.xla | (for English version of Windows) |
| FluidEXL_Graphics.xla     | (for German version of Windows)  |
| LibIdGasMix.dll           |                                  |
| LibIdGasMix.hlp           |                                  |

## Installing FluidEXL *Graphics* for 64-bit Windows®

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

Before you begin, it is best to uninstall any trial version or full version of FluidEXL *Graphics* delivered before June 2010.

After you have downloaded and extracted the zip-file

|                                                |                                  |
|------------------------------------------------|----------------------------------|
| "CD_FluidEXL_Graphics_LibIdGasMix_x64_Eng.zip" | (for English version of Windows) |
| "CD_FluidEXL_Graphics_LibIdGasMix_x64.zip"     | (for German version of Windows)  |

you will see the folder

|                                      |                                  |
|--------------------------------------|----------------------------------|
| CD_FluidEXL_Graphics_LibIdGasMix_Eng | (for English version of Windows) |
| CD_FluidEXL_Graphics_LibIdGasMix     | (for German version of Windows)  |

in your Windows Explorer, Norton Commander etc.

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

Within this folder you will see the following files

|                                        |                                  |
|----------------------------------------|----------------------------------|
| FluidEXL_Graphics_LibIdGasMix_Docu_Eng |                                  |
| FluidEXL_Graphics_Eng.xla              | (for English version of Windows) |
| FluidEXL_Graphics.xla                  | (for German version of Windows)  |
| FluidEXL_Graphics_Eng_Setup_64.msi     | (for English version of Windows) |
| FluidEXL_Graphics_Setup_64.msi         | (for German version of Windows)  |
| LibIdGasMix.dll                        |                                  |
| LibIdGasMix.hlp                        |                                  |
| Setup.exe                              |                                  |

and the folders

vcredist\_x64  
WindowsInstaller3\_1.

In order to run the installation of FluidEXL *Graphics* double-click the file  
Setup.exe.

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

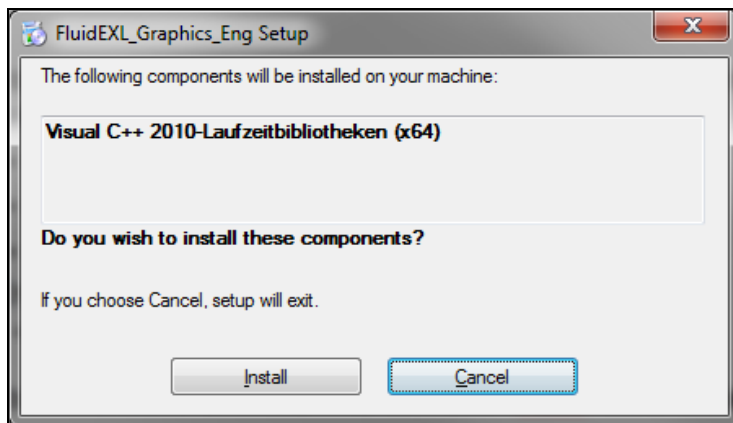


**Figure 2.2:** Installing the "Visual C++ 2010 runtime library (x64)"

Click on "Install" to continue.

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

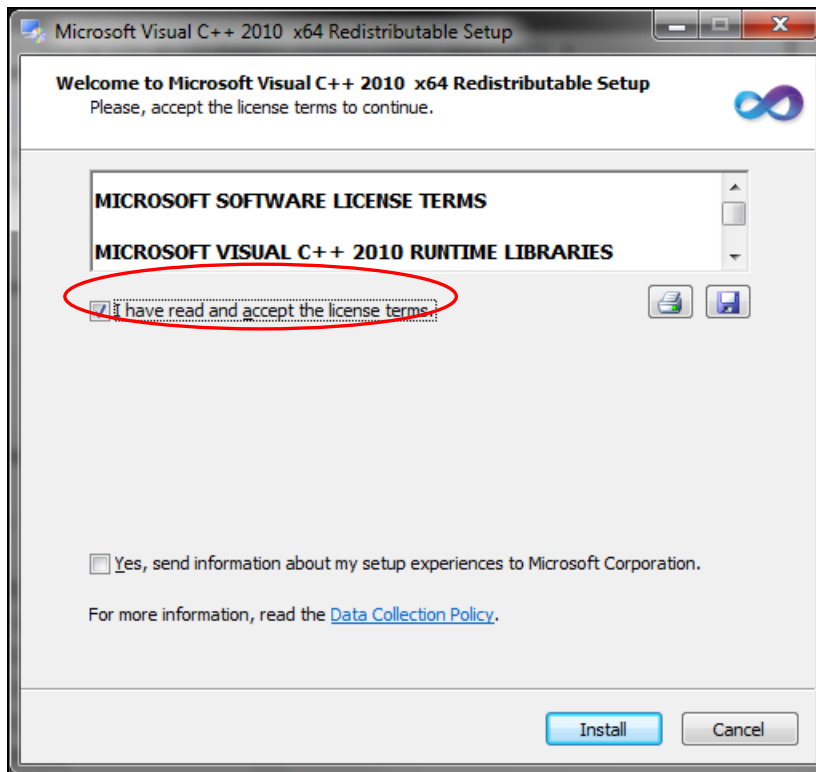


**Figure 2.3:** Accepting the license terms

Now click on "Install" to continue installation.

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

Now the installation of FluidEXL\_Graphics\_Eng\_64 starts with a window noting that the installer will guide you through the installation. Click the "Next >" button to continue.

In the following dialog box, "Select Installation Folder," the default path offered automatically for the installation of FluidEXL\_Graphics is

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

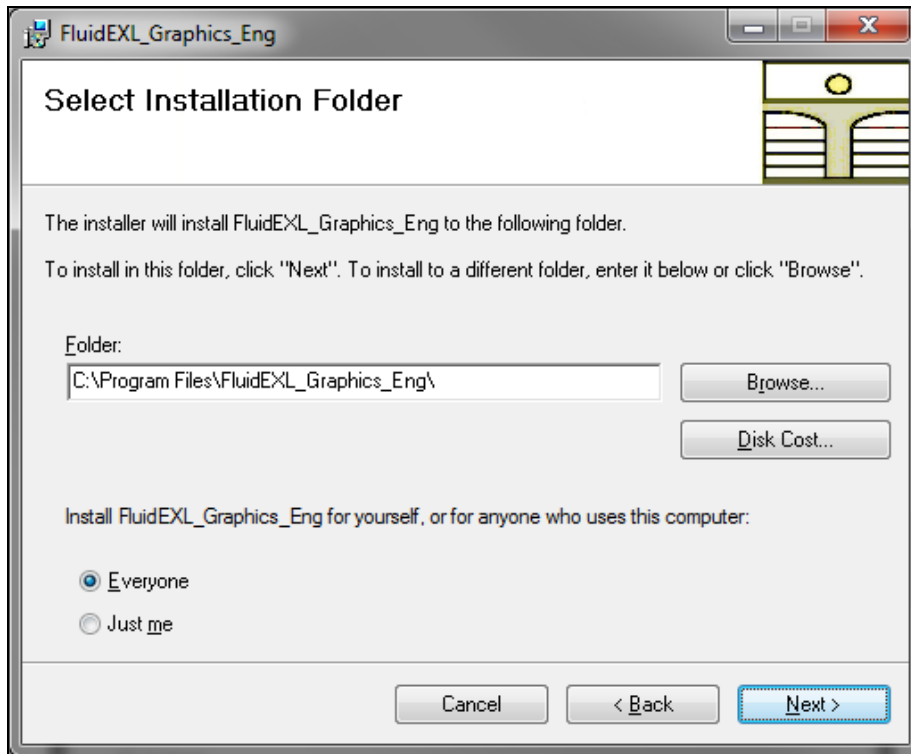


**Figure 2.4:** Choosing the Installation Folder of FluidEXL *Graphics*

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

After FluidEXL *Graphics* has been installed, you will see the sentence "FluidEXL\_Graphics\_Eng has been successfully installed." Confirm this by clicking the "Close" button.

During the installation process the following files

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

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

|                                        |                                  |
|----------------------------------------|----------------------------------|
| C:\Program Files\FuildEXL_Graphics_Eng | (for English version of Windows) |
| C:\Programme\FuildEXL_Graphics         | (for German version of Windows). |

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

In the next step, the files below, found on your CD, must be copied into the chosen destination folder (the standard being

|                                        |                                  |
|----------------------------------------|----------------------------------|
| C:\Program Files\FuildEXL_Graphics_Eng | (for English version of Windows) |
| C:\Programme\FuildEXL_Graphics         | (for German version of Windows)) |

using an appropriate program such as Explorer or Norton Commander:

|                           |                                  |
|---------------------------|----------------------------------|
| FluidEXL_Graphics_Eng.xla | (for English version of Windows) |
| FluidEXL_Graphics.xla     | (for German version of Windows)  |
| LibIdGasMix.dll           |                                  |
| LibIdGasMix.hlp.          |                                  |

## 2.2 Registering FluidEXL<sup>Graphics</sup> as Add-In in Excel<sup>®</sup>

### Registering FluidEXL<sup>Graphics</sup> as Add-In in Excel<sup>®</sup>, versions 2003 or earlier

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

- Click "Tools" in the upper menu bar of Excel<sup>®</sup>.
- Here, click the "Add-Ins..." menu item.  
After a short delay the "Add-Ins" dialog box will appear.
- Click "Browse...."
- In the following dialog box, choose your destination folder (the standard being
 

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

 here select
 

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

and afterwards click "OK."

- Now, the entry
 

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

will appear in the Add-Ins list.

#### **Note:**

*As long as the check box next to the file name "FluidEXL Graphics Eng" is checked, this Add-In will be loaded automatically every time you start Excel<sup>®</sup> until you unmark the box by clicking on it again.*

In order to register "FluidEXL Graphics Eng" as an Add-In, click "OK" in the "Add-Ins" dialog box. Now, the new FluidEXL<sup>Graphics</sup> menu bar will appear in the upper menu area of your Excel<sup>®</sup> screen, marked with a red circle in Figure 2.5.

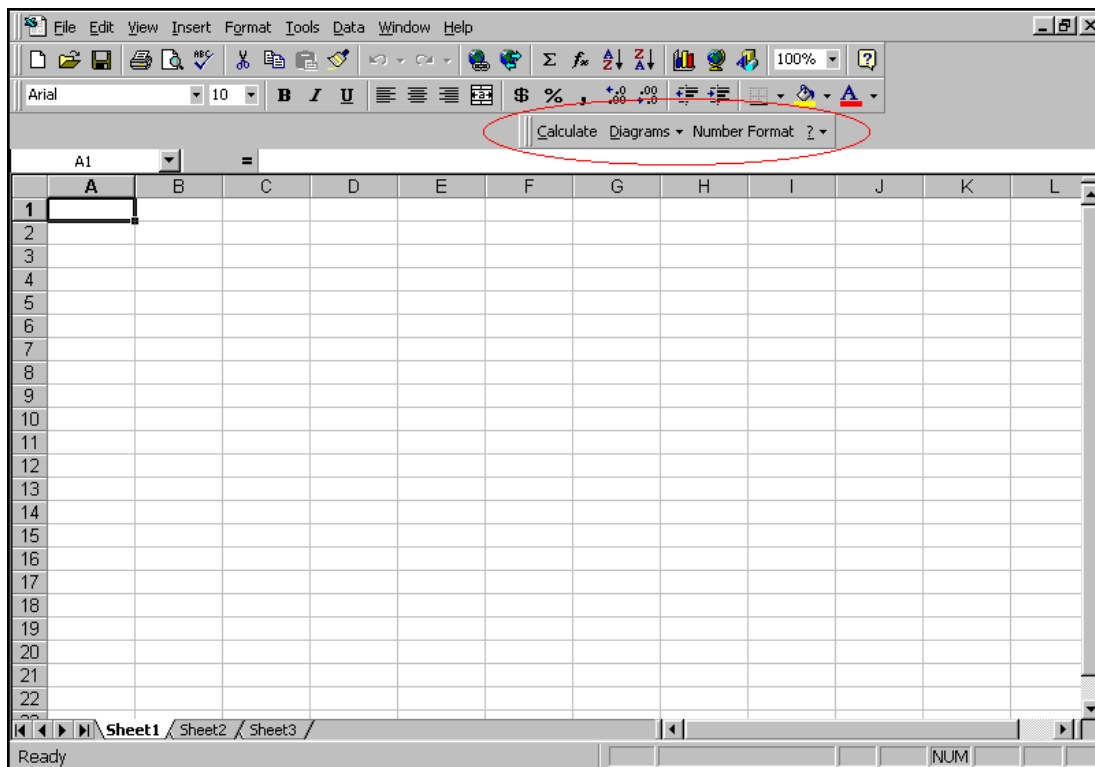


**Figure 2.5:** Menu bar of FluidEXLGraphics

From within Excel you can now select the "Ideal Gas Mixtures LibIdGasMix" DLL library property functions via this menu bar (see part 2.5 on page 2/19).

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

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

- Click the Windows Office® button in the upper left hand corner of Excel®
- Click on the "Excel Options" button in the menu which appears (see Figure 2.6)

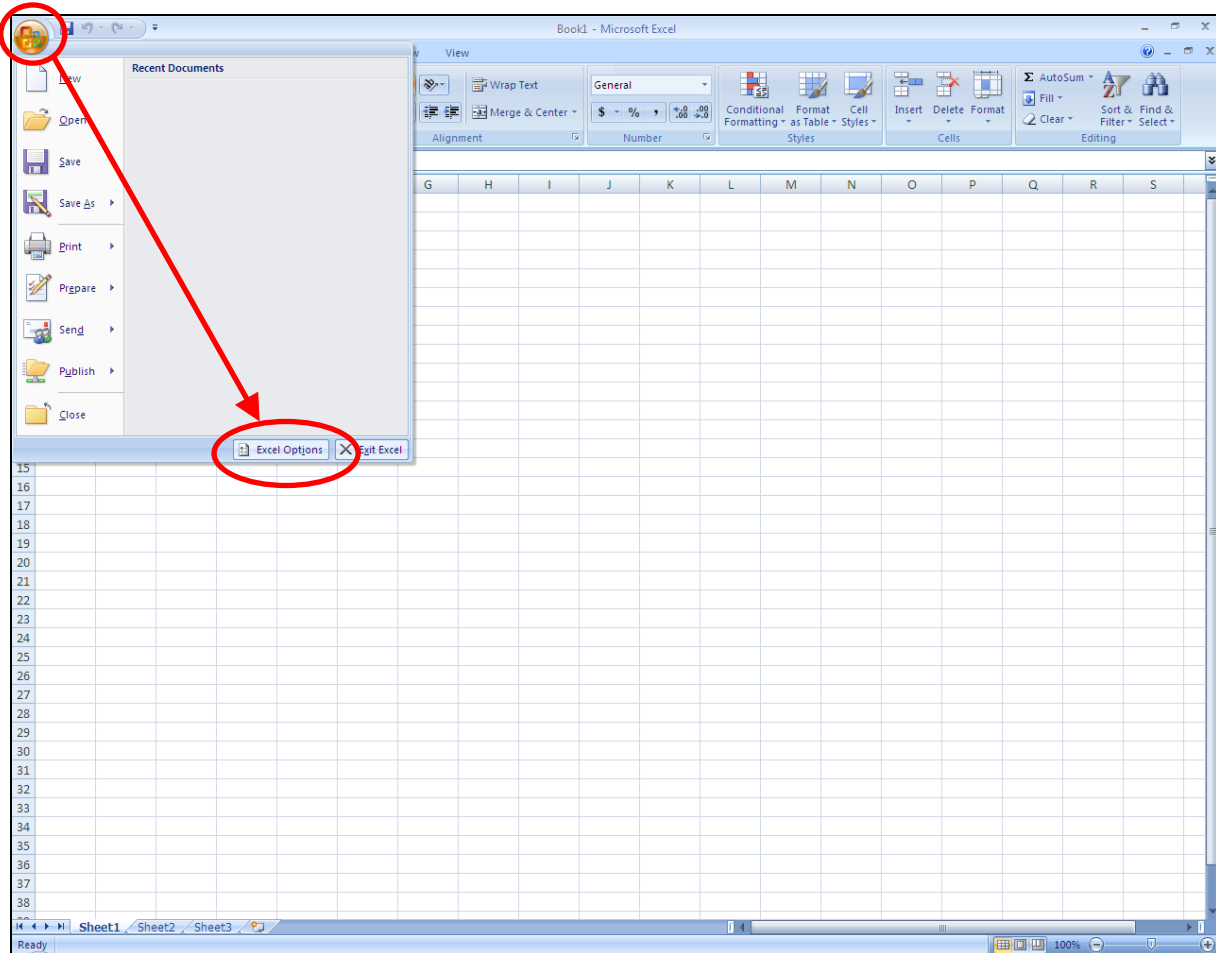


**Figure 2.6:** Registering FluidEXL *Graphics* as Add-In in Excel® 2007

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

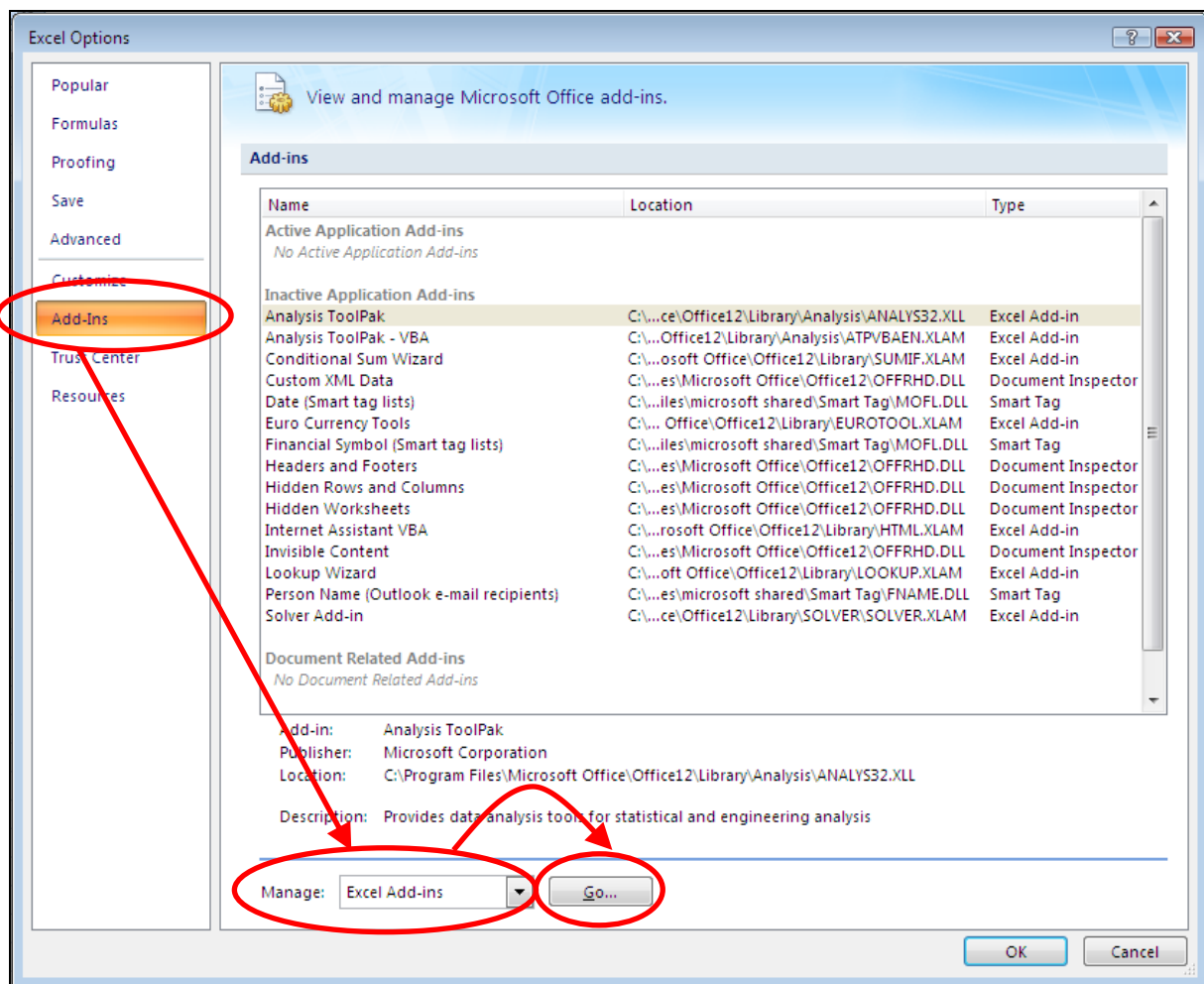


**Figure 2.7:** Dialog window "Excel Options"

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

C:\Program Files\FluidEXL\_Graphics\_Eng (for English version of Windows)  
 C:\Programme\FluidEXL\_Graphics (for German version of Windows);

within that folder click on the file named

"FluidEXL\_Graphics\_Eng.xla" (for English version of Windows)  
 "FluidEXL\_Graphics.xla" (for German version of Windows)

and then hit "OK."

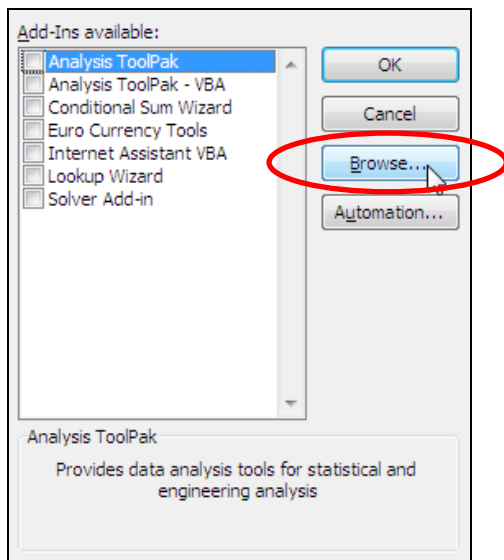


**Figure 2.8:** Dialog window "Add-Ins available"

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

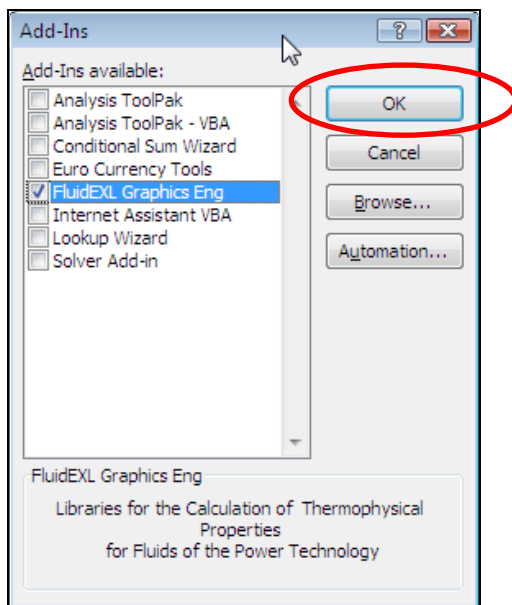


**Figure 2.9:** Dialog window "Add-Ins"

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

In order to use FluidEXL *Graphics* in the following example, click on the menu item "Add-Ins" shown in Figure 2.10.

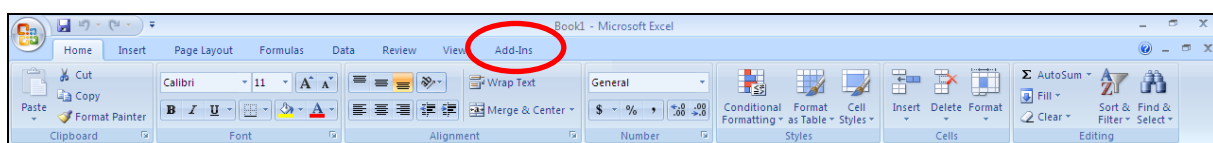


**Figure 2.10:** Menu item "Add-Ins"

In the upper menu region of Excel, the FluidEXL<sup>Graphics</sup> menu bar will appear as marked with the red circle in the next figure.

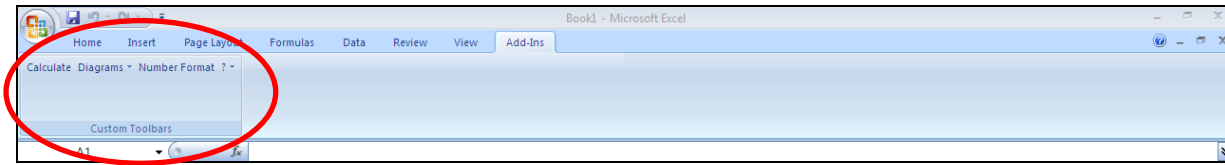


**Figure 2.11:** FluidEXL<sup>Graphics</sup> menu bar

Installation of FluidEXL<sup>Graphics</sup> in Excel<sup>®</sup> (versions 2007 and later) is now finished. FluidEXL<sup>Graphics</sup> can be used analogous to the description for using with earlier Excel<sup>®</sup> versions.

### Adding the LibIdGasMix Library (FluidEXL<sup>Graphics</sup> is already installed)

If FluidEXL<sup>Graphics</sup> has already been installed in the April 2010 version, you only have to copy the following files

|                           |                                  |
|---------------------------|----------------------------------|
| FluidEXL_Graphics_Eng.xla | (for English version of Windows) |
| FluidEXL_Graphics.xla     | (for German version of Windows)  |
| LibIdGasMix.dll           |                                  |
| LibIdGasMix.hlp           |                                  |

provided in the extracted folder

|                                      |                                  |
|--------------------------------------|----------------------------------|
| CD_FluidEXL_Graphics_LibIdGasMix_Eng | (for English version of Windows) |
| CD_FluidEXL_Graphics_LibIdGasMix     | (for German version of Windows)  |

into the folder you have chosen for the installation of FluidEXL<sup>Graphics</sup> (the standard being

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

using an appropriate program such as Explorer<sup>®</sup> or Norton Commander.

From within Excel you can now select the "Ideal Gas Mixtures LibIdGasMix" DLL library property functions via this menu bar (the example calculation can be found in chapter 2.5 on page 2/19).

## 2.3 The FluidEXL<sup>Graphics</sup> Help System

As mentioned earlier, FluidEXL<sup>Graphics</sup> also provides detailed online help functions.

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

"Using the FluidEXL<sup>Graphics</sup> Online-Help in Windows Vista or Windows 7."

For general information in Excel<sup>®</sup>

- Click "Help" in the FluidEXL<sup>Graphics</sup> menu bar.

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

- Click "C<sup>al</sup>culate" in the FluidEXL<sup>Graphics</sup> menu bar.
- Click on the "Ideal Gas Mixtures" library under "Or select a category:" in the "Insert Function" window which will appear.
- Click the "Help on this function" button in the lower left-hand edge of the "Insert Function" window.
- If the "Office Assistant" is active, first double-click "Help on this feature" and in the next menu click "Help on selected function".

If the "LibIdGasMix.hlp" function help cannot be found, confirm the question whether you want to look for it yourself with "Yes". Click on the "LibIdGasMix.hlp" file in the installation menu of FluidEXL<sup>Graphics</sup> in the window which is opened, in the standard case

C:\Program Files\FluidEXL\_Graphics\_Eng (for English version of Windows)

C:\Programme\FluidEXL\_Graphics (for German version of Windows)

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

## Using the FluidEXL<sup>Graphics</sup> Online Help in Windows Vista or Windows 7

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

Open Microsoft Internet Explorer<sup>®</sup> and go to the following address:

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

You will see the following web page:



Figure 2.12: Microsoft<sup>®</sup> Support web page

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

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

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

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

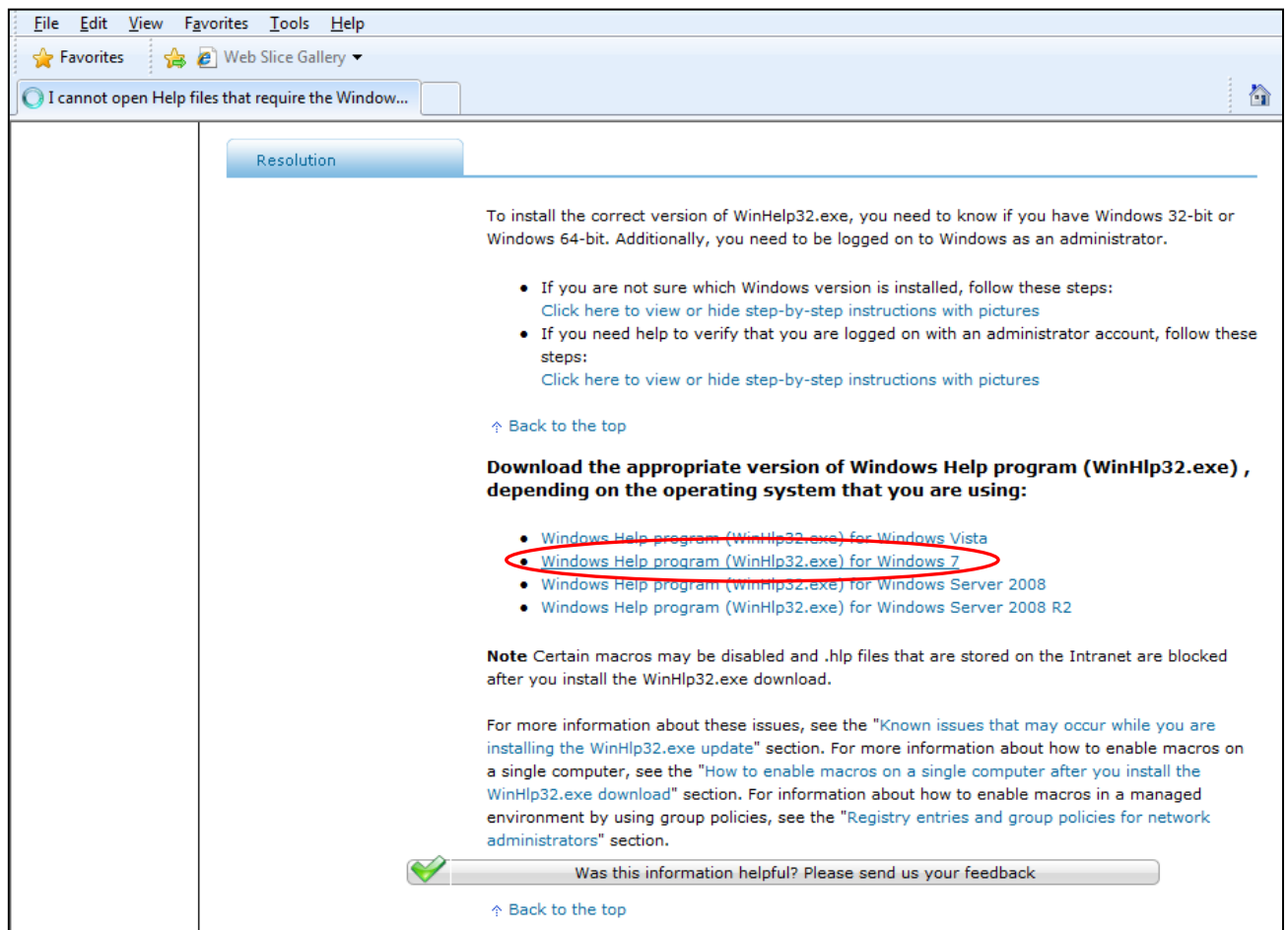


**Figure 2.13:** Selecting your Windows version

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

First, a validation of your Windows License is required.

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

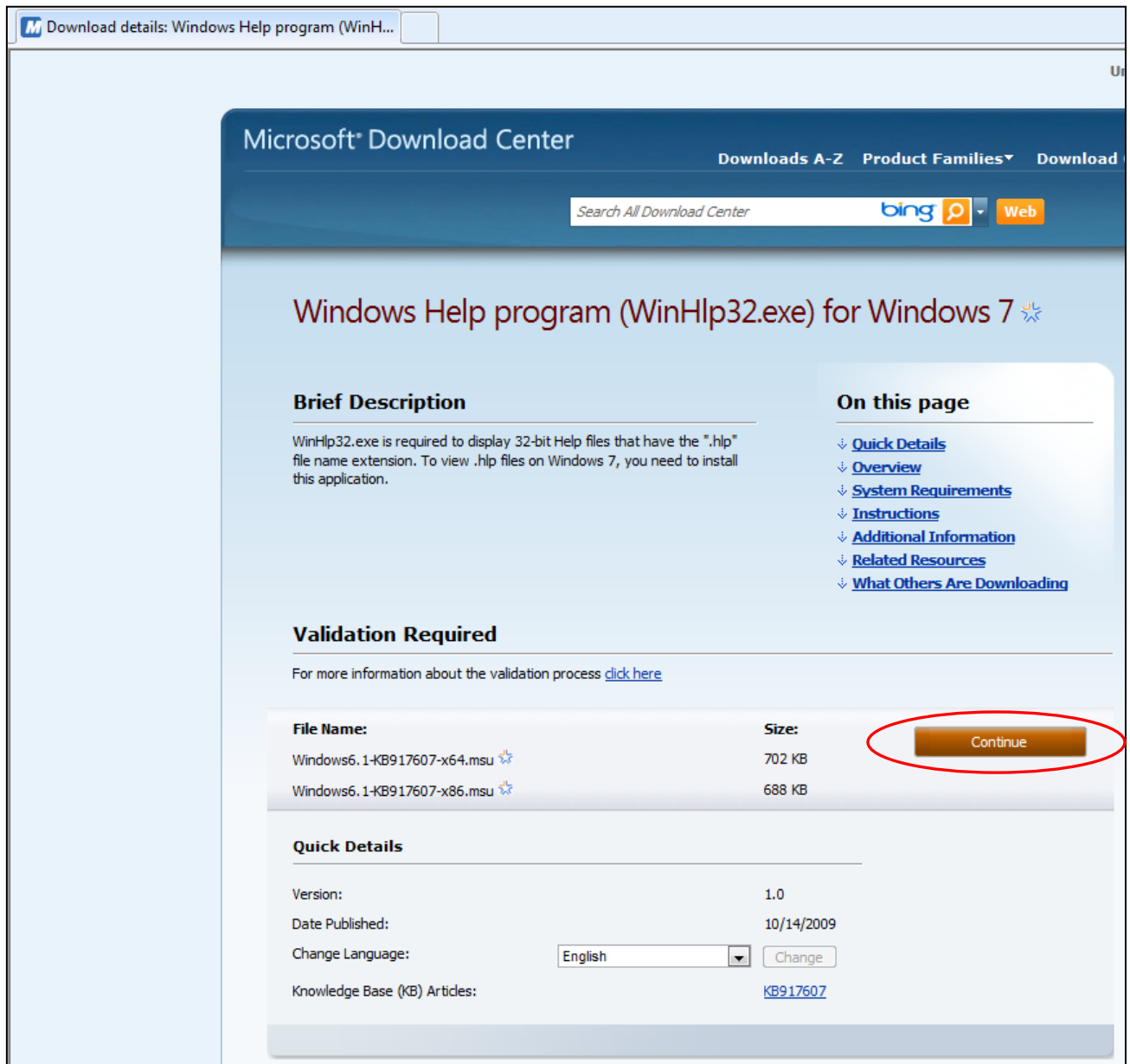


**Figure 2.14:** Microsoft® Download Center

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

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

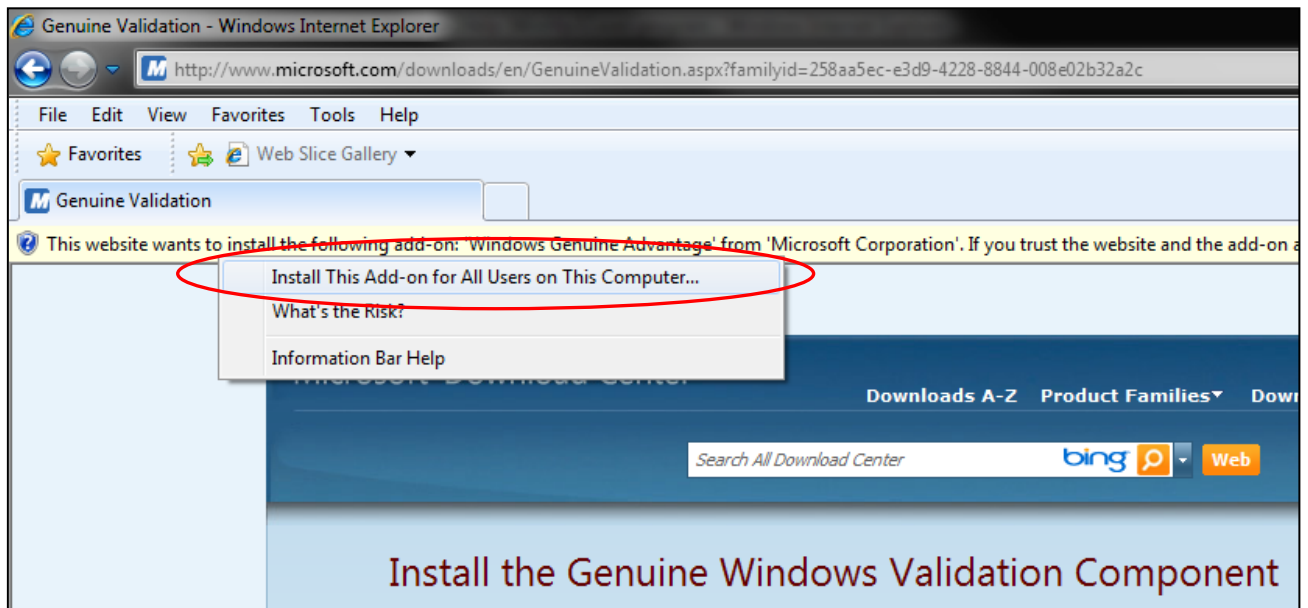


**Figure 2.15:** Installing the Genuine Windows Validation Component

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

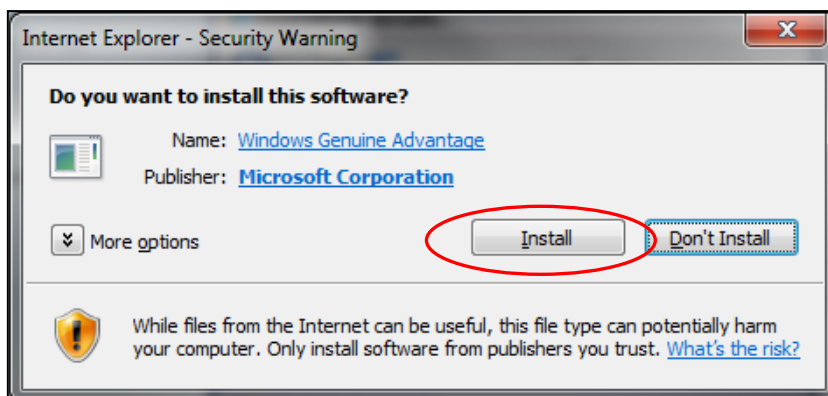


**Figure 2.16:** Internet Explorer – Security Warning

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

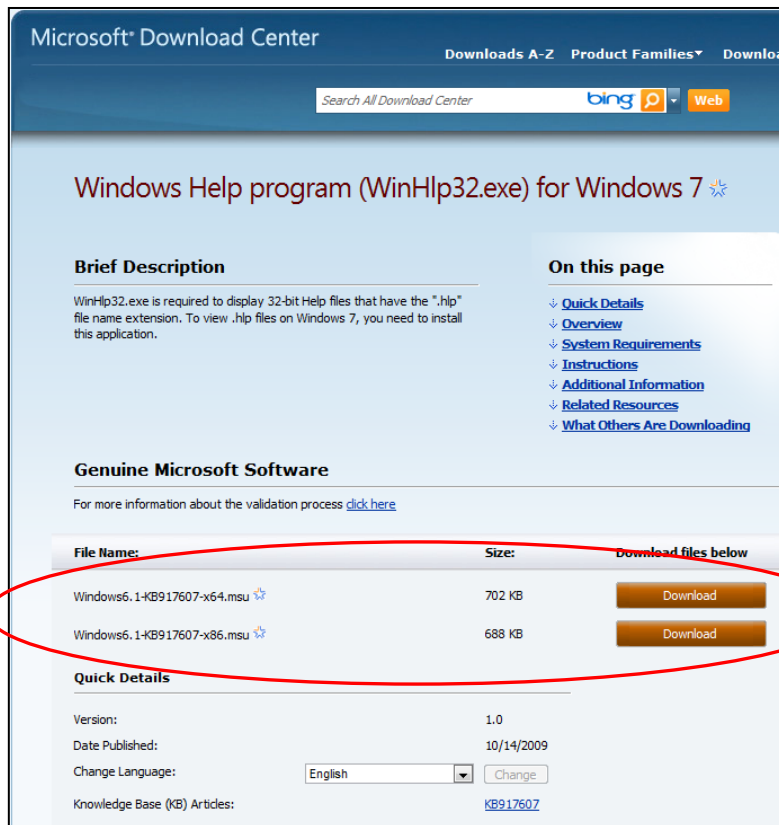


**Figure 2.17:** Downloading the Windows Help program

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

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

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

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

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

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

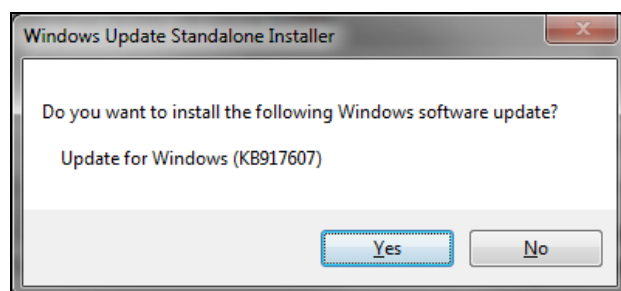


**Figure 2.18:** Windows Update Standalone Installer

In this case, the installation can be continued by clicking the "Yes" button.

*(If you have already installed this update, you will see the message "Update for Windows (KB917607) is already installed on this computer.")*

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

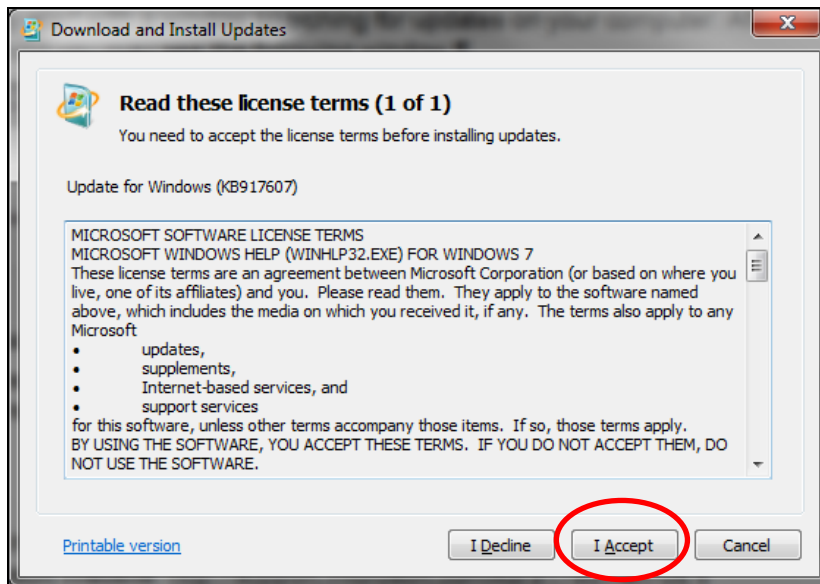


**Figure 2.19:** Windows License Terms

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

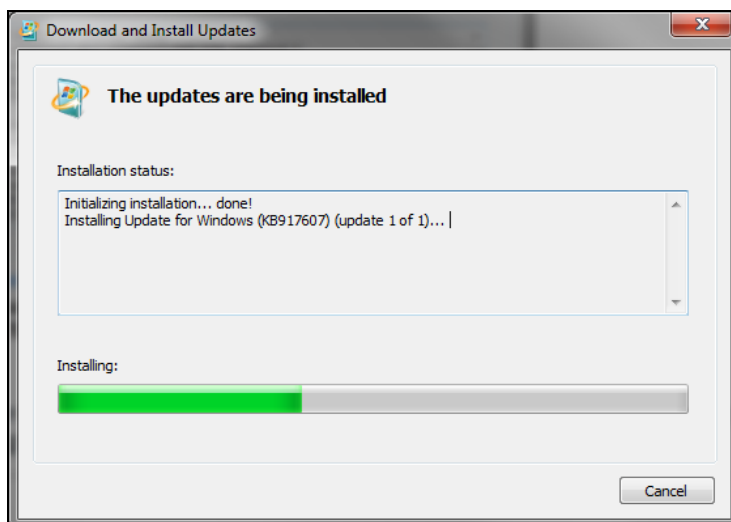


**Figure 2.20:** Installation process

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

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

## 2.4 Licensing the LibIdGasMix Property Library

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

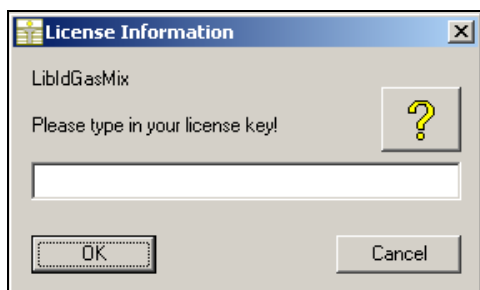


**Figure 2.21:** "License Information" window

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

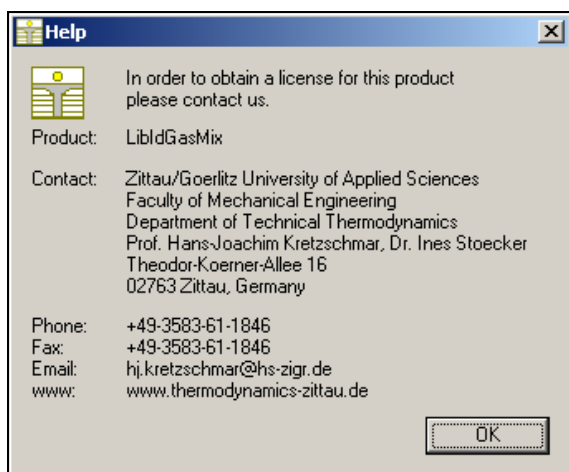


**Figure 2.22:** "Help" window

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

The "License Information" window will appear every time you start Excel unless you uninstall FluidEXL<sup>Graphics</sup> according to the description in section 2.5 of this User's Guide.

Should you not wish to license the LibIdGasMix property library, you have to delete the files

LibIdGasMix.dll  
LibIdGasMix.hlp

in the installation folder of FluidEXL<sup>Graphics</sup> (the standard being

C:\Program Files\FluidEXL\_Graphics\_Eng (for English version of Windows)  
C:\Programme\FluidEXL\_Graphics (for German version of Windows)

using an appropriate program such as Explorer<sup>®</sup> or Norton Commander.

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

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 FluidEXL<sup>Graphics</sup>.

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

The description of the calculation is given for the application of FluidEXL<sup>Graphics</sup> in Excel<sup>®</sup> 2003. The procedure is analogous to Excel 7.0, 97, 2000, and XP<sup>®</sup>.

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 Excel, if you did not start it before.

- Prepare an Excel book as shown below:

|    | A       | B                             | C            | D                | E    | F        | G       | H          |
|----|---------|-------------------------------|--------------|------------------|------|----------|---------|------------|
| 1  | Gas No. | Mixture gas                   | xsi in kg/kg | psi in kmol/kmol | Type | p in bar | t in °C | h in kJ/kg |
| 2  | 1       | Ar                            |              |                  |      |          |         |            |
| 3  | 2       | Ne                            |              |                  |      |          |         |            |
| 4  | 3       | N <sub>2</sub>                |              |                  |      |          |         |            |
| 5  | 4       | O <sub>2</sub>                |              |                  |      |          |         |            |
| 6  | 5       | CO                            |              |                  |      |          |         |            |
| 7  | 6       | CO <sub>2</sub>               |              |                  |      |          |         |            |
| 8  | 7       | H <sub>2</sub> O              |              |                  |      |          |         |            |
| 9  | 8       | SO <sub>2</sub>               |              |                  |      |          |         |            |
| 10 | 9       | air (dry)                     |              |                  |      |          |         |            |
| 11 | 10      | atmospheric nitrogen          |              |                  |      |          |         |            |
| 12 | 11      | NO                            |              |                  |      |          |         |            |
| 13 | 12      | H <sub>2</sub> S              |              |                  |      |          |         |            |
| 14 | 13      | OH                            |              |                  |      |          |         |            |
| 15 | 14      | CH <sub>3</sub> OH            |              |                  |      |          |         |            |
| 16 | 15      | CH <sub>4</sub>               |              |                  |      |          |         |            |
| 17 | 16      | C <sub>2</sub> H <sub>4</sub> |              |                  |      |          |         |            |
| 18 | 17      | C <sub>2</sub> H <sub>6</sub> |              |                  |      |          |         |            |
| 19 | 18      | C <sub>3</sub> H <sub>6</sub> |              |                  |      |          |         |            |
| 20 | 19      | C <sub>3</sub> H <sub>8</sub> |              |                  |      |          |         |            |
| 21 | 20      | n-butane                      |              |                  |      |          |         |            |
| 22 | 21      | Iso-butane                    |              |                  |      |          |         |            |
| 23 | 22      | C <sub>6</sub> H <sub>6</sub> |              |                  |      |          |         |            |
| 24 | 23      | H <sub>2</sub>                |              |                  |      |          |         |            |
| 25 | 24      | He                            |              |                  |      |          |         |            |
| 26 | 25      | NH <sub>3</sub>               |              |                  |      |          |         |            |
| 27 | 26      | free                          |              |                  |      |          |         |            |
| 28 | 27      | free                          |              |                  |      |          |         |            |
| 29 | 28      | free                          |              |                  |      |          |         |            |
| 30 | 29      | free                          |              |                  |      |          |         |            |
| 31 | 30      | F <sub>2</sub>                |              |                  |      |          |         |            |

**Figure 2.23:** Preparing an Excel book

- Enter a value for  $p$  in bar into cell F2.  
(Range of validity:  $p = 0.01$  mbar up to 50 bar)  
⇒ e.g.: Enter 1.45 into cell F2.
- Enter a value for  $t$  in °C into cell G2.  
(Range of validity:  $t = -73.15$  °C ... 3026.85 °C)  
⇒ e.g.: Enter 100 into cell G2.
- Enter a specification for "Type" into cell E2 which depends on whether the entry is 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  $\psi_1 \dots \psi_{30}$ .  
⇒ e.g.: Enter 1 into cell E2.

- Enter the values for the given mass fractions  $\xi_1 \dots \xi_{30}$  of the mixture gases into the range of cells from C2 to C31:

|            |                          |                                |                                |               |
|------------|--------------------------|--------------------------------|--------------------------------|---------------|
| $\xi_1$    | for argon                | Ar                             | $\Rightarrow$ e.g.: Enter 0    | into cell C2  |
| $\xi_2$    | for neon                 | Ne                             | $\Rightarrow$ e.g.: Enter 0.12 | into cell C3  |
| $\xi_3$    | for nitrogen             | N <sub>2</sub>                 | $\Rightarrow$ e.g.: Enter 0    | into cell C4  |
| $\xi_4$    | for oxygen               | O <sub>2</sub>                 | $\Rightarrow$ e.g.: Enter 0    | into cell C5  |
| $\xi_5$    | for carbon monoxide      | CO                             | $\Rightarrow$ e.g.: Enter 0    | into cell C6  |
| $\xi_6$    | for carbon dioxide       | CO <sub>2</sub>                | $\Rightarrow$ e.g.: Enter 0    | into cell C7  |
| $\xi_7$    | for steam                | H <sub>2</sub> O               | $\Rightarrow$ e.g.: Enter 0.09 | into cell C8  |
| $\xi_8$    | for sulfur dioxide       | SO <sub>2</sub>                | $\Rightarrow$ e.g.: Enter 0    | into cell C9  |
| $\xi_9$    | for air - dry            |                                | $\Rightarrow$ e.g.: Enter 0.21 | into cell C10 |
| $\xi_{10}$ | for atmospheric nitrogen |                                | $\Rightarrow$ e.g.: Enter 0    | into cell C11 |
| $\xi_{11}$ | for nitrogen oxide       | NO                             | $\Rightarrow$ e.g.: Enter 0    | into cell C12 |
| $\xi_{12}$ | for hydrogen sulfide     | H <sub>2</sub> S               | $\Rightarrow$ e.g.: Enter 0    | into cell C13 |
| $\xi_{13}$ | for hydroxyl             | OH                             | $\Rightarrow$ e.g.: Enter 0    | into cell C14 |
| $\xi_{14}$ | for methanol             | CH <sub>3</sub> OH             | $\Rightarrow$ e.g.: Enter 0    | into cell C15 |
| $\xi_{15}$ | for methane              | CH <sub>4</sub>                | $\Rightarrow$ e.g.: Enter 0    | into cell C16 |
| $\xi_{16}$ | for ethylene             | C <sub>2</sub> H <sub>4</sub>  | $\Rightarrow$ e.g.: Enter 0.39 | into cell C17 |
| $\xi_{17}$ | for ethane               | C <sub>2</sub> H <sub>6</sub>  | $\Rightarrow$ e.g.: Enter 0    | into cell C18 |
| $\xi_{18}$ | for propylene            | C <sub>3</sub> H <sub>6</sub>  | $\Rightarrow$ e.g.: Enter 0    | into cell C19 |
| $\xi_{19}$ | for propane              | C <sub>3</sub> H <sub>8</sub>  | $\Rightarrow$ e.g.: Enter 0    | into cell C20 |
| $\xi_{20}$ | for n-butane             | C <sub>4</sub> H <sub>10</sub> | $\Rightarrow$ e.g.: Enter 0.14 | into cell C21 |
| $\xi_{21}$ | for Iso-butane           | C <sub>4</sub> H <sub>10</sub> | $\Rightarrow$ e.g.: Enter 0    | into cell C22 |
| $\xi_{22}$ | for benzene              | C <sub>6</sub> H <sub>6</sub>  | $\Rightarrow$ e.g.: Enter 0    | into cell C23 |
| $\xi_{23}$ | for hydrogen             | H <sub>2</sub>                 | $\Rightarrow$ e.g.: Enter 0.05 | into cell C24 |
| $\xi_{24}$ | for helium               | He                             | $\Rightarrow$ e.g.: Enter 0    | into cell C25 |
| $\xi_{25}$ | for ammonia              | NH <sub>3</sub>                | $\Rightarrow$ e.g.: Enter 0    | into cell C26 |
| $\xi_{26}$ | free                     |                                | $\Rightarrow$ e.g.: Enter 0    | into cell C27 |
| $\xi_{27}$ | free                     |                                | $\Rightarrow$ e.g.: Enter 0    | into cell C28 |
| $\xi_{28}$ | free                     |                                | $\Rightarrow$ e.g.: Enter 0    | into cell C29 |
| $\xi_{29}$ | free                     |                                | $\Rightarrow$ e.g.: Enter 0    | into cell C30 |
| $\xi_{30}$ | for fluorine             | F <sub>2</sub>                 | $\Rightarrow$ e.g.: Enter 0    | into cell C31 |

Your Excel book should now look like the following figure:

|    | A       | B                             | C            | D                | E    | F        | G       | H          |
|----|---------|-------------------------------|--------------|------------------|------|----------|---------|------------|
| 1  | Gas No. | Mixture gas                   | xsi in kg/kg | psi in kmol/kmol | Type | p in bar | t in °C | h in kJ/kg |
| 2  | 1       | Ar                            | 0            |                  | 1    | 1.45     | 100     |            |
| 3  | 2       | Ne                            | 0.12         |                  |      |          |         |            |
| 4  | 3       | N <sub>2</sub>                | 0            |                  |      |          |         |            |
| 5  | 4       | O <sub>2</sub>                | 0            |                  |      |          |         |            |
| 6  | 5       | CO                            | 0            |                  |      |          |         |            |
| 7  | 6       | CO <sub>2</sub>               | 0            |                  |      |          |         |            |
| 8  | 7       | H <sub>2</sub> O              | 0.09         |                  |      |          |         |            |
| 9  | 8       | SO <sub>2</sub>               | 0            |                  |      |          |         |            |
| 10 | 9       | air (dry)                     | 0.21         |                  |      |          |         |            |
| 11 | 10      | atmospheric nitrogen          | 0            |                  |      |          |         |            |
| 12 | 11      | NO                            | 0            |                  |      |          |         |            |
| 13 | 12      | H <sub>2</sub> S              | 0            |                  |      |          |         |            |
| 14 | 13      | OH                            | 0            |                  |      |          |         |            |
| 15 | 14      | CH <sub>3</sub> OH            | 0            |                  |      |          |         |            |
| 16 | 15      | CH <sub>4</sub>               | 0            |                  |      |          |         |            |
| 17 | 16      | C <sub>2</sub> H <sub>4</sub> | 0.39         |                  |      |          |         |            |
| 18 | 17      | C <sub>2</sub> H <sub>6</sub> | 0            |                  |      |          |         |            |
| 19 | 18      | C <sub>3</sub> H <sub>6</sub> | 0            |                  |      |          |         |            |
| 20 | 19      | C <sub>3</sub> H <sub>8</sub> | 0            |                  |      |          |         |            |
| 21 | 20      | n-butane                      | 0.14         |                  |      |          |         |            |
| 22 | 21      | Iso-butane                    | 0            |                  |      |          |         |            |
| 23 | 22      | C <sub>6</sub> H <sub>6</sub> | 0            |                  |      |          |         |            |
| 24 | 23      | H <sub>2</sub>                | 0.05         |                  |      |          |         |            |
| 25 | 24      | He                            | 0            |                  |      |          |         |            |
| 26 | 25      | NH <sub>3</sub>               | 0            |                  |      |          |         |            |
| 27 | 26      | free                          | 0            |                  |      |          |         |            |
| 28 | 27      | free                          | 0            |                  |      |          |         |            |
| 29 | 28      | free                          | 0            |                  |      |          |         |            |
| 30 | 29      | free                          | 0            |                  |      |          |         |            |
| 31 | 30      | F <sub>2</sub>                | 0            |                  |      |          |         |            |

**Figure 2.24:** Prepared Excel book

**Note!**

*It is not necessary to enter the value 0 (zero) as Excel considers an empty cell to be equal zero.*

*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  $\psi_{30} = 1$ , or as a single gas. If it is entered as a mixture gas with  $\xi_{30} < 1$  or  $\psi_{30} < 1$  the value calculated will result in 30999.*

Go on like follows:

- Click the cell into which the enthalpy  $h$  in kJ/kg is to be calculated.  
⇒ e.g.: Click the H2 cell.
- Click "Calculate" in the FluidEXL *Graphics* menu bar. The "Insert Function" window appears:

|    | A       | B                             | C            | D                | E    | F        | G       | H          |
|----|---------|-------------------------------|--------------|------------------|------|----------|---------|------------|
| 1  | Gas No. | Mixture gas                   | xsi in kg/kg | psi in kmol/kmol | Type | p in bar | t in °C | h in kJ/kg |
| 2  | 1       | Ar                            | 0            |                  | 1    | 1.45     | 100     | =          |
| 3  | 2       | Ne                            | 0.12         |                  |      |          |         |            |
| 4  | 3       | N <sub>2</sub>                | 0            |                  |      |          |         |            |
| 5  | 4       | O <sub>2</sub>                | 0            |                  |      |          |         |            |
| 6  | 5       | CO                            | 0            |                  |      |          |         |            |
| 7  | 6       | CO <sub>2</sub>               | 0            |                  |      |          |         |            |
| 8  | 7       | H <sub>2</sub> O              | 0.09         |                  |      |          |         |            |
| 9  | 8       | SO <sub>2</sub>               | 0            |                  |      |          |         |            |
| 10 | 9       | air (dry)                     | 0.21         |                  |      |          |         |            |
| 11 | 10      | atmospheric nitrogen          | 0            |                  |      |          |         |            |
| 12 | 11      | NO                            | 0            |                  |      |          |         |            |
| 13 | 12      | H <sub>2</sub> S              | 0            |                  |      |          |         |            |
| 14 | 13      | OH                            | 0            |                  |      |          |         |            |
| 15 | 14      | CH <sub>3</sub> OH            | 0            |                  |      |          |         |            |
| 16 | 15      | CH <sub>4</sub>               | 0            |                  |      |          |         |            |
| 17 | 16      | C <sub>2</sub> H <sub>4</sub> | 0.39         |                  |      |          |         |            |
| 18 | 17      | C <sub>2</sub> H <sub>6</sub> | 0            |                  |      |          |         |            |
| 19 | 18      | C <sub>3</sub> H <sub>6</sub> | 0            |                  |      |          |         |            |
| 20 | 19      | C <sub>3</sub> H <sub>8</sub> | 0            |                  |      |          |         |            |
| 21 | 20      | n-butane                      | 0.14         |                  |      |          |         |            |
| 22 | 21      | Iso-butane                    | 0            |                  |      |          |         |            |
| 23 | 22      | C <sub>6</sub> H <sub>6</sub> | 0            |                  |      |          |         |            |
| 24 | 23      | H <sub>2</sub>                | 0.05         |                  |      |          |         |            |
| 25 | 24      | He                            | 0            |                  |      |          |         |            |
| 26 | 25      | NH <sub>3</sub>               | 0            |                  |      |          |         |            |
| 27 | 26      | free                          | 0            |                  |      |          |         |            |
| 28 | 27      | free                          | 0            |                  |      |          |         |            |
| 29 | 28      | free                          | 0            |                  |      |          |         |            |
| 30 | 29      | free                          | 0            |                  |      |          |         |            |
| 31 | 30      | F <sub>2</sub>                | 0            |                  |      |          |         |            |

Insert Function

Search for a function:

Type a brief description of what you want to do and then click Go

Go

Or select a category:

Ideal Gas Mixtures LibIdGasMix

Select a function:

eta\_pt\_igas  
eta\_pt\_igmix  
h\_pt\_igas  
**h\_pt\_igmix**  
kappa\_pt\_igas  
kappa\_pt\_igmix  
lambda\_pt\_igas

**h\_pt\_igmix( p in bar ; t in °C ; 1->xsi 0->psi ; comp(1:30) )**  
Enthalpy h in kJ/kg

[Help on this function](#)

OK

Cancel

**Figure 2.25:** Choice of library and function name

- Search and click the "Ideal Gas Mixtures LibIdGasMix" library under "Or select a category:".
- Search and click the function to be calculated under "Select a function:"  
⇒ e.g.: Click h\_pt\_igmix.
- Click "OK".

The "Function Arguments" window appears.

- The cursor is located next to "p in bar" (see Figure 2.26).

**Figure 2.26:** Input menu for the function

- Click the cell that entails the  $p$  value, or enter the cell number of  $p$ , or enter the value of  $p$  directly.  
 ⇒ e.g.: Click the cell F2.  
 The cell number is entered automatically next to "p in bar".
- Situate the cursor next to "t in °C" in the input window.
- Click the cell that entails the  $t$  value, or enter the cell number of  $t$  or enter the value of  $t$  directly.  
 ⇒ e.g.: Enter the G2 cell number.  
 The cell G2 number appears in the input window.
- Situate the cursor next to "1->xsi 0->psi" in the input window.
- Click the cell with the value for type, or enter the cell number of the value for type, or enter the value for type directly.  
 Type = 1 for entering the composition in mass fractions  $\xi_1 \dots \xi_{30}$   
 Type = 0 for entering the composition in mole fractions or volume fractions  $\psi_1 \dots \psi_{30}$   
 ⇒ e.g.: Click the cell E2.
- Situate the cursor next to "comp(1:30)" in the input window.
- Click the cell C2 which contains the mass fraction  $\xi_1$  (argon) and keep the mouse button pressed.  
 The cursor now changes to a cross.
- Select all further cells that contain the fractions up to  $\xi_{30}$  (cell C31) keeping the mouse button pressed. Release the mouse button.  
 Next to "comp(1:30)" now appears the selected range C2:C31.  
 Alternatively, the cells that entail the mass or mole fractions could have been entered directly into the input window as C2:C31 range.

Proceed analogous if the mole fractions  $\psi_1 \dots \psi_{30}$  of the mixture gases are given. In this case, the cells D2:D31 have to be selected and entered.

**Note:**

*The mass or mole fractions of the mixture gases can be located one below the other in one column, or next to each other in one row, as shown in the example beneath. However, the accompanying cells have to be put directly one after the other and in the correct order.*

The window should now look like the following figure:

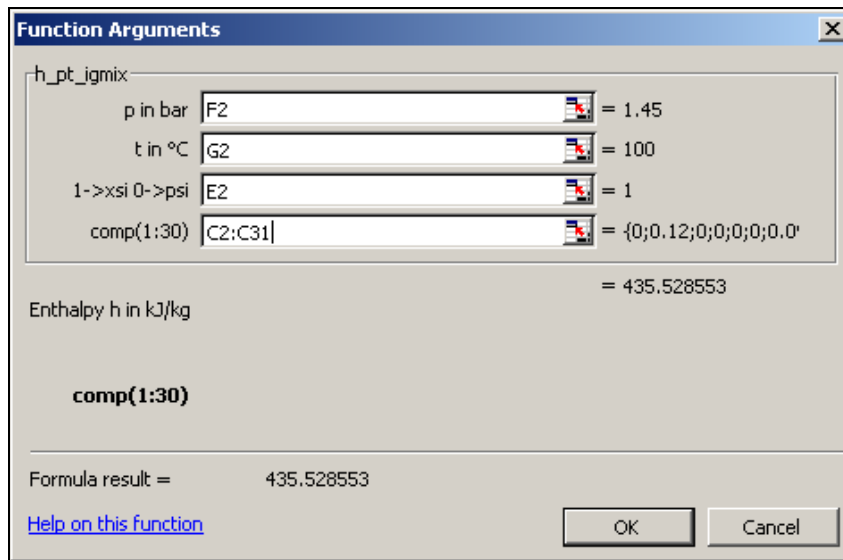


**Figure 2.27:** Input menu showing the result

- Click "OK".

⇒ The result in our sample calculation here is: 435.528553 in kJ/kg.

The calculation of  $h = f(p, t, \xi_1 \dots \xi_{30})$  has thus been carried out. You can now arbitrarily change the values for  $p$ ,  $t$ , and  $\xi_1 \dots \xi_{30}$  in the appropriate cells. The sum of the mass fractions  $\xi_1 \dots \xi_{30}$  always has to result in 1. The specific enthalpy of the gas mixture is recalculated and updated every time you change the data. This shows that the Excel data flow and the DLL calculations are working together successfully.

**Important!**

*LibIdGasMix checks internally whether the partial pressures of the mixture gasses 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 Example: Calculation of the Mole Fraction

$\psi_i = f(i, \xi_1 \dots \xi_{30})$  of the Gas  $i$  within the Gas Mixture

Resuming the example in part 2.5, now we will calculate the mole fraction of ethylene ( $C_2H_4$ ).

The values for the mass fractions  $\xi_1 \dots \xi_{30}$  are already listed in the cells C2 to C31.

Carry out the following steps:

- Click the cell into which the mole fraction in kmol/kmol of the desired mixture gas should be calculated.

⇒ e.g.: Click the cell D17 entailing  $\psi_{16}$  for  $C_2H_4$ .

- Click "Calculate" in the FluidEXL *Graphics* menu bar.

The "Insert Function" window appears.

- The "Ideal Gas Mixtures LibIdGasMix" library under "Or select a category:" has already been marked as we used it for the calculation in part 2.5.

- Search and click the function to be calculated under "Select a function:" as shown in the next Figure:

⇒ e.g.: Click `psi_igas_xsi_igmix`.

|    | A       | B                             | C            | D                | E    | F        | G       | H          | I | J |
|----|---------|-------------------------------|--------------|------------------|------|----------|---------|------------|---|---|
| 1  | Gas No. | Mixture gas                   | xsi in kg/kg | psi in kmol/kmol | Type | p in bar | t in °C | h in kJ/kg |   |   |
| 2  | 1       | Ar                            | 0            |                  | 1    | 1.45     | 100     |            |   |   |
| 3  | 2       | Ne                            | 0.12         |                  |      |          |         |            |   |   |
| 4  | 3       | N <sub>2</sub>                | 0            |                  |      |          |         |            |   |   |
| 5  | 4       | O <sub>2</sub>                | 0            |                  |      |          |         |            |   |   |
| 6  | 5       | CO                            | 0            |                  |      |          |         |            |   |   |
| 7  | 6       | CO <sub>2</sub>               | 0            |                  |      |          |         |            |   |   |
| 8  | 7       | H <sub>2</sub> O              | 0.09         |                  |      |          |         |            |   |   |
| 9  | 8       | SO <sub>2</sub>               | 0            |                  |      |          |         |            |   |   |
| 10 | 9       | air (dry)                     | 0.21         |                  |      |          |         |            |   |   |
| 11 | 10      | atmospheric nitrogen          | 0            |                  |      |          |         |            |   |   |
| 12 | 11      | NO                            | 0            |                  |      |          |         |            |   |   |
| 13 | 12      | H <sub>2</sub> S              | 0            |                  |      |          |         |            |   |   |
| 14 | 13      | OH                            | 0            |                  |      |          |         |            |   |   |
| 15 | 14      | CH <sub>3</sub> OH            | 0            |                  |      |          |         |            |   |   |
| 16 | 15      | CH <sub>4</sub>               | 0            |                  |      |          |         |            |   |   |
| 17 | 16      | C <sub>2</sub> H <sub>4</sub> | 0.39         | =                |      |          |         |            |   |   |
| 18 | 17      | C <sub>2</sub> H <sub>6</sub> | 0            |                  |      |          |         |            |   |   |
| 19 | 18      | C <sub>3</sub> H <sub>6</sub> | 0            |                  |      |          |         |            |   |   |
| 20 | 19      | C <sub>3</sub> H <sub>8</sub> | 0            |                  |      |          |         |            |   |   |
| 21 | 20      | n-butane                      | 0.14         |                  |      |          |         |            |   |   |
| 22 | 21      | Iso-butane                    | 0            |                  |      |          |         |            |   |   |
| 23 | 22      | C <sub>6</sub> H <sub>6</sub> | 0            |                  |      |          |         |            |   |   |
| 24 | 23      | H <sub>2</sub>                | 0.05         |                  |      |          |         |            |   |   |
| 25 | 24      | He                            | 0            |                  |      |          |         |            |   |   |
| 26 | 25      | NH <sub>3</sub>               | 0            |                  |      |          |         |            |   |   |
| 27 | 26      | free                          | 0            |                  |      |          |         |            |   |   |
| 28 | 27      | free                          | 0            |                  |      |          |         |            |   |   |
| 29 | 28      | free                          | 0            |                  |      |          |         |            |   |   |
| 30 | 29      | free                          | 0            |                  |      |          |         |            |   |   |
| 31 | 30      | F <sub>2</sub>                | 0            |                  |      |          |         |            |   |   |

**Insert Function**

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

Or select a category: Ideal Gas Mixtures LibIdGasMix

Select a function:  
 p\_tv\_igmix  
 Pr\_pt\_igas  
 Pr\_pt\_igmix  
**psi\_igas\_xsi\_igmix**  
 R\_igas  
 R\_igmix  
 rho\_pt\_igas

**psi\_igas\_xsi\_igmix( igas (1...30) ; xsi(1:30) )**  
 Mole fraction for igas from mass fractions

[Help on this function](#) OK Cancel

**Figure 2.28:** Choice of library and function name

- Click "OK".

- The cursor is now located next to "igas (1...30)".
- You can now enter the value for the gas number either by clicking the cell with the value for the gas number, by entering the name of the cell with the value for the gas number, or by entering the value for the gas number directly.

⇒ e.g.: Enter A17 that entails the gas number 16 for ethylene.

- Click next to "xsi (1:30)" in the "Insert Function" window.
- Click the C2 cell that entails the mass fraction  $\xi_1$  (Argon) and keep the mouse button pressed.

The cursor is a cross now.

- Select all further cells that entail the mass fractions up to  $\xi_{30}$  (C31) and release the mouse button.

Next to "xsi(1:30)", the selected range of C2:C31 is entered automatically.

If there are further mole fractions to be calculated later on, we recommend adding the \$ sign in front of the characters and numbers in order to secure the order of cells: \$C2:\$C\$31.

The window should now look like the following figure:

|    | A       | B                             | C            | D                | E    | F        | G       | H          | I | J | K |
|----|---------|-------------------------------|--------------|------------------|------|----------|---------|------------|---|---|---|
| 1  | Gas No. | Mixture gas                   | xsi in kg/kg | psi in kmol/kmol | Type | p in bar | t in °C | h in kJ/kg |   |   |   |
| 2  | 1       | Ar                            | 0            |                  | 1    | 1.45     | 100     |            |   |   |   |
| 3  | 2       | Ne                            | 0.12         |                  |      |          |         |            |   |   |   |
| 4  | 3       | N <sub>2</sub>                | 0            |                  |      |          |         |            |   |   |   |
| 5  | 4       | O <sub>2</sub>                | 0            |                  |      |          |         |            |   |   |   |
| 6  | 5       | CO                            | 0            |                  |      |          |         |            |   |   |   |
| 7  | 6       | CO <sub>2</sub>               | 0            |                  |      |          |         |            |   |   |   |
| 8  | 7       | H <sub>2</sub> O              | 0.09         |                  |      |          |         |            |   |   |   |
| 9  | 8       | SO <sub>2</sub>               | 0            |                  |      |          |         |            |   |   |   |
| 10 | 9       | air (dry)                     | 0.21         |                  |      |          |         |            |   |   |   |
| 11 | 10      | atmospheric nitrogen          | 0            |                  |      |          |         |            |   |   |   |
| 12 | 11      | NO                            | 0            |                  |      |          |         |            |   |   |   |
| 13 | 12      | H <sub>2</sub> S              | 0            |                  |      |          |         |            |   |   |   |
| 14 | 13      | OH                            | 0            |                  |      |          |         |            |   |   |   |
| 15 | 14      | CH <sub>3</sub> OH            | 0            |                  |      |          |         |            |   |   |   |
| 16 | 15      | CH <sub>4</sub>               | 0            |                  |      |          |         |            |   |   |   |
| 17 | 16      | C <sub>2</sub> H <sub>4</sub> | 0.39         | (A17;C2:C31)     |      |          |         |            |   |   |   |
| 18 | 17      | C <sub>2</sub> H <sub>6</sub> | 0            |                  |      |          |         |            |   |   |   |
| 19 | 18      | C <sub>3</sub> H <sub>6</sub> | 0            |                  |      |          |         |            |   |   |   |
| 20 | 19      | C <sub>3</sub> H <sub>8</sub> | 0            |                  |      |          |         |            |   |   |   |
| 21 | 20      | n-butane                      | 0.14         |                  |      |          |         |            |   |   |   |
| 22 | 21      | Iso-butane                    | 0            |                  |      |          |         |            |   |   |   |
| 23 | 22      | C <sub>6</sub> H <sub>6</sub> | 0            |                  |      |          |         |            |   |   |   |
| 24 | 23      | H <sub>2</sub>                | 0.05         |                  |      |          |         |            |   |   |   |
| 25 | 24      | He                            | 0            |                  |      |          |         |            |   |   |   |
| 26 | 25      | NH <sub>3</sub>               | 0            |                  |      |          |         |            |   |   |   |
| 27 | 26      | free                          | 0            |                  |      |          |         |            |   |   |   |
| 28 | 27      | free                          | 0            |                  |      |          |         |            |   |   |   |
| 29 | 28      | free                          | 0            |                  |      |          |         |            |   |   |   |
| 30 | 29      | free                          | 0            |                  |      |          |         |            |   |   |   |
| 31 | 30      | F <sub>2</sub>                | 0            |                  |      |          |         |            |   |   |   |

**Function Arguments**

psi\_igas\_xsi\_igmix

igas (1...30)  = 16

xsi(1:30)  = {0;0.12;0;0;0;0;0.09

Mole fraction for igas from mass fractions

**xsi(1:30)**

Formula result = 0.234403958

[Help on this function](#)

OK Cancel

**Figure 2.29:** Input menu for the function

- Click "OK".
- ⇒ The result in our sample calculation here is: 0.234403958 in kmol/kmol.

In order to calculate the mole fractions of further mixture gases proceed as follows:

- Click D17, the cell which we have just calculated.
- Situate the mouse pointer onto the cell's lower right-hand edge.  
A cross is displayed.
- Keep the left mouse button pressed and pull the cross as far as D31.  
Around the cells selected a frame is displayed.
- Release the left mouse button.

In the range of D18:D31 the calculated mole fractions of gases number 17 to 30 are displayed.

- In order to calculate the mole fractions of the gases number 1 to 15, proceed analogous:
- Click D17, the cell to be calculated.
- Situate the mouse pointer onto the cell's lower right-hand edge.  
A cross is displayed.
- Keep the left mouse button pressed and pull the cross as far as D2.  
A frame is displayed around the selected cells.
- Release the left mouse button.

In the range of D2:D16 the calculated mole fractions of gases number 1 to 15 are displayed (see next figure).

|    | A       | B                             | C            | D                | E    | F        | G       | H          |
|----|---------|-------------------------------|--------------|------------------|------|----------|---------|------------|
| 1  | Gas No. | Mixture gas                   | xsi in kg/kg | psi in kmol/kmol | Type | p in bar | t in °C | h in kJ/kg |
| 2  | 1       | Ar                            | 0            | 0                | 1    | 1.45     | 100     |            |
| 3  | 2       | Ne                            | 0.12         | 0.10026484       |      |          |         |            |
| 4  | 3       | N <sub>2</sub>                | 0            | 0                |      |          |         |            |
| 5  | 4       | O <sub>2</sub>                | 0            | 0                |      |          |         |            |
| 6  | 5       | CO                            | 0            | 0                |      |          |         |            |
| 7  | 6       | CO <sub>2</sub>               | 0            | 0                |      |          |         |            |
| 8  | 7       | H <sub>2</sub> O              | 0.09         | 0.084233261      |      |          |         |            |
| 9  | 8       | SO <sub>2</sub>               | 0            | 0                |      |          |         |            |
| 10 | 9       | air (dry)                     | 0.21         | 0.122264777      |      |          |         |            |
| 11 | 10      | atmospheric nitrogen          | 0            | 0                |      |          |         |            |
| 12 | 11      | NO                            | 0            | 0                |      |          |         |            |
| 13 | 12      | H <sub>2</sub> S              | 0            | 0                |      |          |         |            |
| 14 | 13      | OH                            | 0            | 0                |      |          |         |            |
| 15 | 14      | CH <sub>3</sub> OH            | 0            | 0                |      |          |         |            |
| 16 | 15      | CH <sub>4</sub>               | 0            | 0                |      |          |         |            |
| 17 | 16      | C <sub>2</sub> H <sub>4</sub> | 0.39         | 0.234403958      |      |          |         |            |
| 18 | 17      | C <sub>2</sub> H <sub>6</sub> | 0            | 0                |      |          |         |            |
| 19 | 18      | C <sub>3</sub> H <sub>6</sub> | 0            | 0                |      |          |         |            |
| 20 | 19      | C <sub>3</sub> H <sub>8</sub> | 0            | 0                |      |          |         |            |
| 21 | 20      | n-butane                      | 0.14         | 0.040613271      |      |          |         |            |
| 22 | 21      | Iso-butane                    | 0            | 0                |      |          |         |            |
| 23 | 22      | C <sub>6</sub> H <sub>6</sub> | 0            | 0                |      |          |         |            |
| 24 | 23      | H <sub>2</sub>                | 0.05         | 0.418219893      |      |          |         |            |
| 25 | 24      | He                            | 0            | 0                |      |          |         |            |
| 26 | 25      | NH <sub>3</sub>               | 0            | 0                |      |          |         |            |
| 27 | 26      | free                          | 0            | 0                |      |          |         |            |
| 28 | 27      | free                          | 0            | 0                |      |          |         |            |
| 29 | 28      | free                          | 0            | 0                |      |          |         |            |
| 30 | 29      | free                          | 0            | 0                |      |          |         |            |
| 31 | 30      | F <sub>2</sub>                | 0            | 0                |      |          |         |            |

**Figure 2.30:** Excel book with results

Gases with mass fractions equal to zero also have mole fractions equal to zero.

The gas numbers 25 to 29 are not defined and therefore result in –xx999, for which xx corresponds to the gas number as listed in table 1.

Because of its chemical properties, fluorine cannot be calculated. Thus, the result -30999 will be displayed in cell D31.

## 2.7 Example: Calculation of the Enthalpy $h = f(p, t, \text{igas})$ of igas

Now we will calculate, step by step, the specific enthalpy  $h$  of n-butane as a function of pressure  $p = 1.45$  bar and temperature  $t = 100$  °C.

The description of the calculation is given for the application of FluidEXL<sup>Graphics</sup> in Excel XP<sup>®</sup>. The procedure is similar to Excel 7.0, 97, 2000, 2007 and 2010.

According to table 1 in part 1.1, n-butane represents the gas number  $\text{igas} = 20$  in the LibIdGasMix property library.

Please carry out the following steps:

- Start Excel.
- Prepare a sheet in Excel similar to the table shown below:

|   | A       | B        | C        | D       | E          | F |
|---|---------|----------|----------|---------|------------|---|
| 1 | Gas no. | Gas      | p in bar | t in °C | h in kJ/kg |   |
| 2 |         | n-butane |          |         |            |   |
| 3 |         |          |          |         |            |   |
| 4 |         |          |          |         |            |   |
| 5 |         |          |          |         |            |   |
| 6 |         |          |          |         |            |   |
| 7 |         |          |          |         |            |   |

**Figure 2.31:** Preparing an Excel book

- Enter a value for  $p$  in bar into a cell.  
(Range of validity:  $p = 0.01$  mbar up to 50 bar)  
⇒ e.g.: Enter 1.45 into the cell C2.
- Enter a value for  $t$  in °C into a cell.  
(Range of validity:  $t = -73.15$  °C ... 3026.85 °C)  
⇒ e.g.: Enter 100 into the cell D2.
- Enter the gas number of  $\text{igas}$  into a cell.  
(Gas number of  $\text{igas}$ : from 1 up to 30)  
⇒ e.g.: Enter 20 into the cell A2.

Your sheet should now look like the table shown in the figure below:

|   | A       | B        | C        | D       | E          | F |
|---|---------|----------|----------|---------|------------|---|
| 1 | Gas no. | Gas      | p in bar | t in °C | h in kJ/kg |   |
| 2 | 20      | n-butane | 1.45     | 100     |            |   |
| 3 |         |          |          |         |            |   |
| 4 |         |          |          |         |            |   |
| 5 |         |          |          |         |            |   |
| 6 |         |          |          |         |            |   |

**Figure 2.32:** Prepared Excel book

### **Note!**

Currently the gases with the numbers 26 to 29 do not exist. If you enter one of these numbers the calculation will result in "-xx0999", for which "xx" corresponds to the faulty gas number.

- Click the cell in which the enthalpy  $h$  in kJ/kg calculated is to be displayed.  
⇒ e.g.: Click the cell E2.
- Click "Calculate" in the menu bar of FluidEXL<sup>Graphics</sup>.

Now, the "Insert Function" window appears (see Figure 2.31).

- Search and click the "Ideal Gas Mixtures LibIdGasMix" library under "Or select a category:" in the upper part of the window.
- Search and click the function to be calculated under "Select a function:" right below:  
⇒ e.g.: Click the "[h\\_pt\\_igas](#)" function.

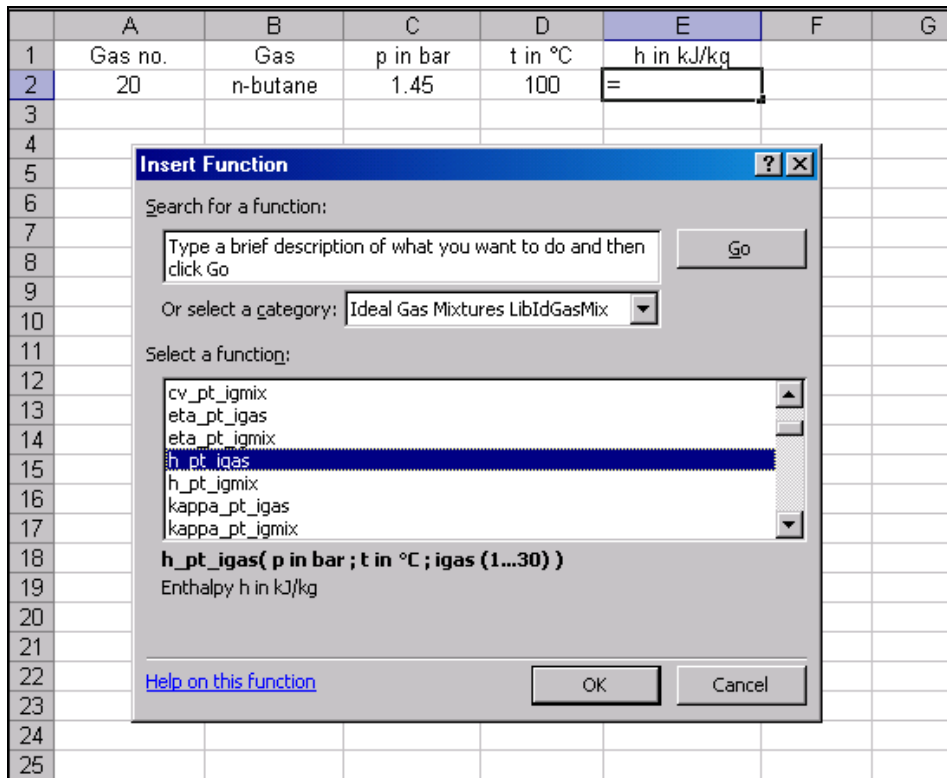


**Figure 2.33:** Choice of library and function name

- Click "OK".
- The cursor is now situated next to " $p$  in bar".
- You can now enter the value for  $p$  either by clicking the cell with the value for  $p$ , by entering the name of the cell with the value for  $p$ , or by entering the value for  $p$  directly.  
⇒ e.g.: Click the cell C2.  
The C2 cell number is displayed in the input window.
- Click next to " $t$  in °C".
- You can now enter the value for  $t$  either by clicking the cell with the value for  $t$ , by entering the name of the cell with the value for  $t$ , or by entering the value for  $t$  directly.  
⇒ e.g.: Click the cell D2.  
The cell number of D2 is displayed in the input window.
- Click next to "igas (1 ... 30)".
- You can now enter the value with the gas number either by clicking the cell with the gas number, by entering the name of the cell with the gas number, or by entering the gas number directly.  
⇒ e.g.: Click the A2 cell.  
The A2 cell number is displayed in the input window.

The window should now look like the following example sheet:

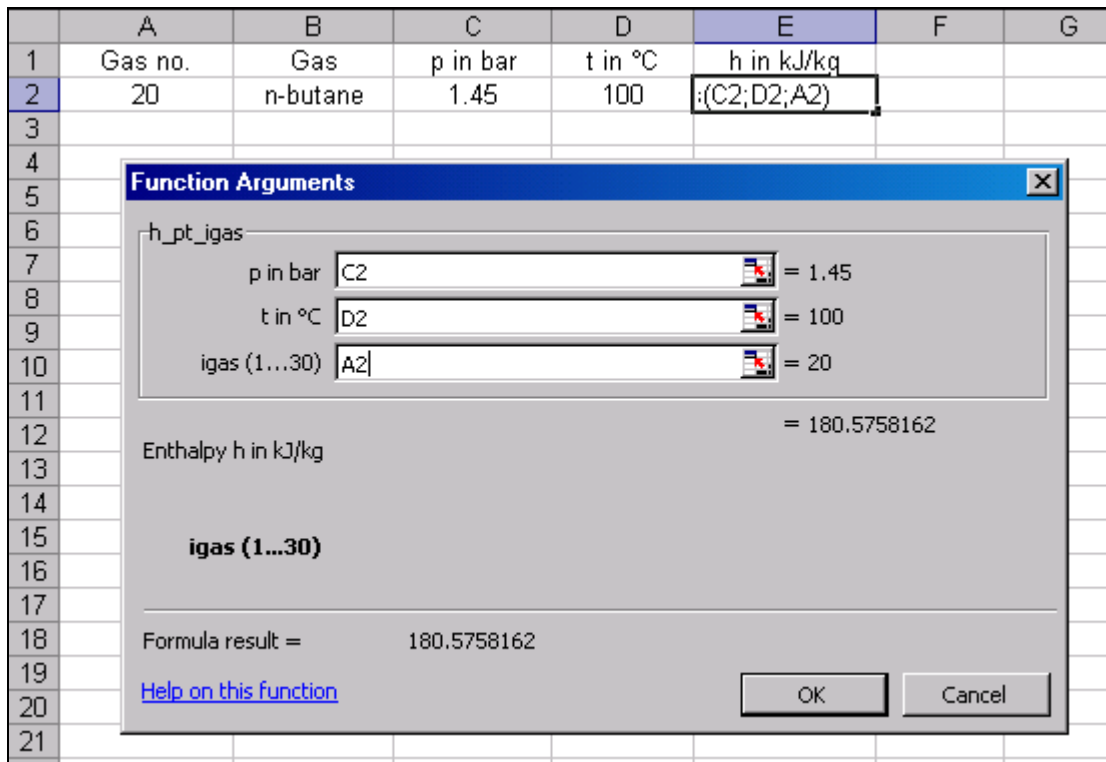


**Figure 2.34:** Input menu showing the result

- Click "OK".

⇒ The result in our example calculation here is:  $h = 180.5758162$  kJ/kg.

The calculation of the specific enthalpy  $h$  of n-butane has thus been carried out. You can now arbitrarily change the values for pressure, temperature, and the gas number in the appropriate cells. The specific enthalpy of the single gas is recalculated every time you change the data. This shows that the Excel data flow and the LibIdGasMix DLL calculations are working together successfully.

**Note:**

*LibIdGasMix internally checks whether the given pressure is higher than the saturation pressure at the given temperature. If this is the case, "-xx999" will be displayed as result, for which "xx" corresponds to the gas number, e.g., -7999 for steam.*

## Number Formats

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

Changes can be made as follows:

- Click the cell or select and click on the cells you wish to format.  
(In empty cells the new format will be applied once a value has been entered.)
- Click "Number Format" in the FluidEXL *Graphics* menu bar.
- Select the desired number format in the dialog box which appears:
  - "STD – Standard": Insignificant zeros behind the decimal point are not shown.
  - "FIX – Fixed Number of Digits": All set decimal places are shown, including insignificant zeros.
  - "SCI – Scientific Format": Numbers are always shown in the exponential form with the set number of decimal places.
- Set the "Number of decimal places" by entering the number into the appropriate window.
- Confirm this by clicking the "OK" button.

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

|     |           |
|-----|-----------|
| STD | 1.23      |
| FIX | 1.230     |
| SCI | 1.230E+00 |

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

## 2.8 Removing FluidEXL *Graphics*

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

LibIdGasMix.dll  
LibIdGasMix.hlp

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

C:\Program Files\FluidEXL\_Graphics\_Eng (for English version of Windows)  
C:\Programme\FluidEXL\_Graphics (for German version of Windows)

by using an appropriate program such as Explorer<sup>®</sup>, Windows, or Norton Commander.

### Unregistering FluidEXL *Graphics* as Add-In in Excel<sup>®</sup>, versions 2003 or earlier

To remove FluidEXL *Graphics* completely, proceed as follows: First the registration of

FluidEXL\_Graphics\_Eng.xla

has to be cancelled in Excel<sup>®</sup>.

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

FluidEXL\_Graphics\_Eng.xla (for English version of Windows)  
FluidEXL\_Graphics.xla (for German version of Windows)

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

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

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

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

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

Within the next step delete the files

LibIdGasMix.dll  
LibIdGasMix.hlp

in the directory selected for the installation of FluidEXL *Graphics* (the standard being

C:\Program Files\FluidEXL\_Graphics\_Eng (for English version of Windows)  
C:\Programme\FluidEXL\_Graphics (for German version of Windows)

using an appropriate program such as Explorer<sup>®</sup> or Norton Commander.

In order to remove FluidEXL *Graphics* from Windows and the hard disk drive, click "Start" in the Windows task bar, select "Settings" and click "Control Panel". Now double-click on "Add or Remove Programs". In the list box of the "Add/Remove Programs" window that appears select

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

by clicking on it and click the "Add/Remove..." button. In the following dialog box click

"Automatic" and thereafter "Next >". Click "Finish" in the "Perform Uninstall" window. Answer the question whether all shared components shall be removed with "Yes to All". Finally, close the "Add/Remove Programs" and "Control Panel" windows.

Now FluidEXL<sup>Graphics</sup> has been removed.

### Unregistering FluidEXL<sup>Graphics</sup> as Add-In in Excel<sup>®</sup> 2007 (or later versions)

In order to unregister the FluidEXL<sup>Graphics</sup> Add-In in Excel<sup>®</sup> 2007 start Excel and carry out the following commands:

- Click the Windows Office<sup>®</sup> button in the upper left corner of Excel
- Click on the "Excel Options" button in the menu which appears

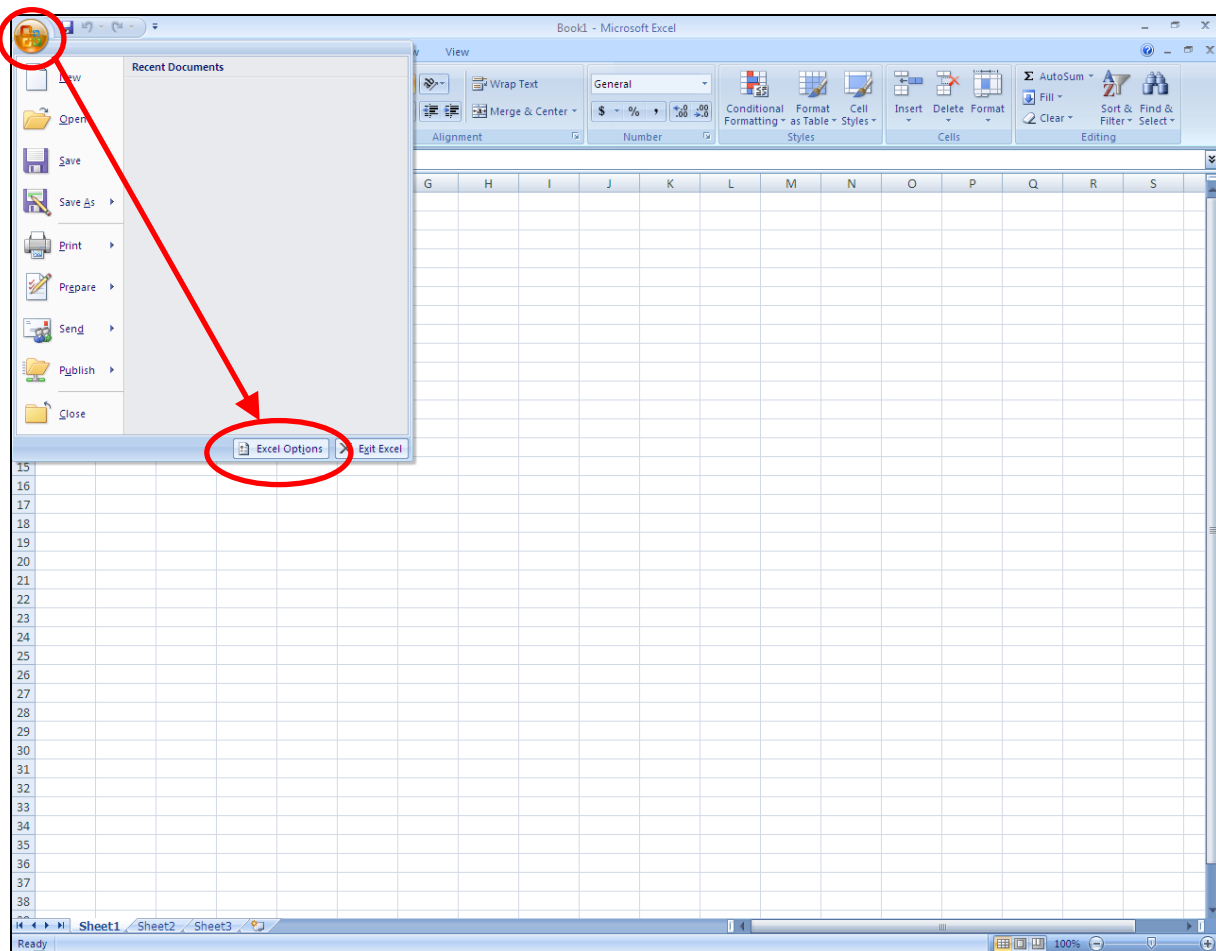


**Figure 2.35:** Unregistering FluidEXL<sup>Graphics</sup> as Add-In in Excel<sup>®</sup> 2007

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

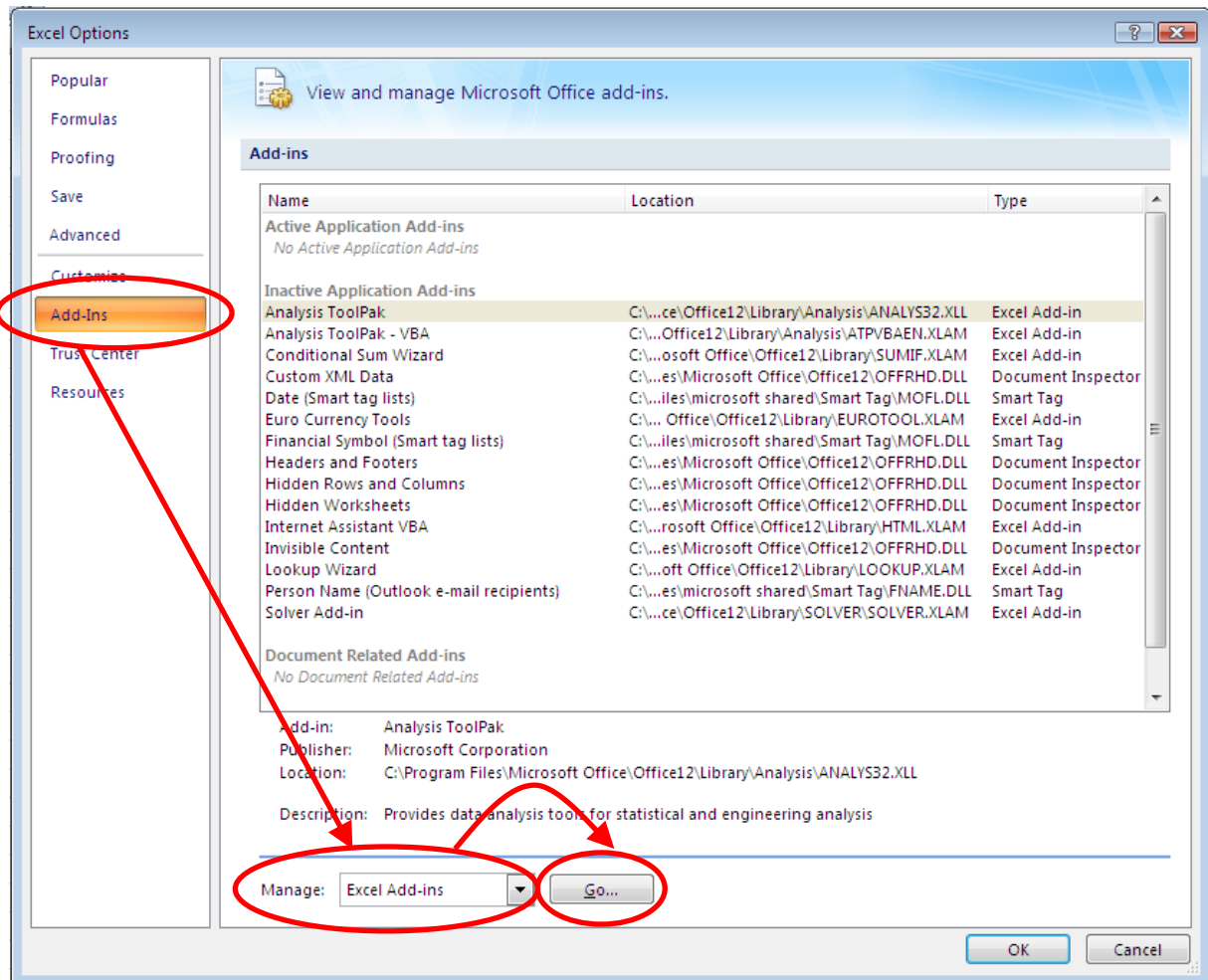


**Figure 2.36:** Dialog window "Add-Ins"

- If it is not shown in the list automatically, chose and click "Excel Add-ins" next to "Manage:" in the lower area of the menu
- Afterwards click the "Go..." button
- Remove the checkmark in front of

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

"FluidEXL Graphics" (for German version of Windows)

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

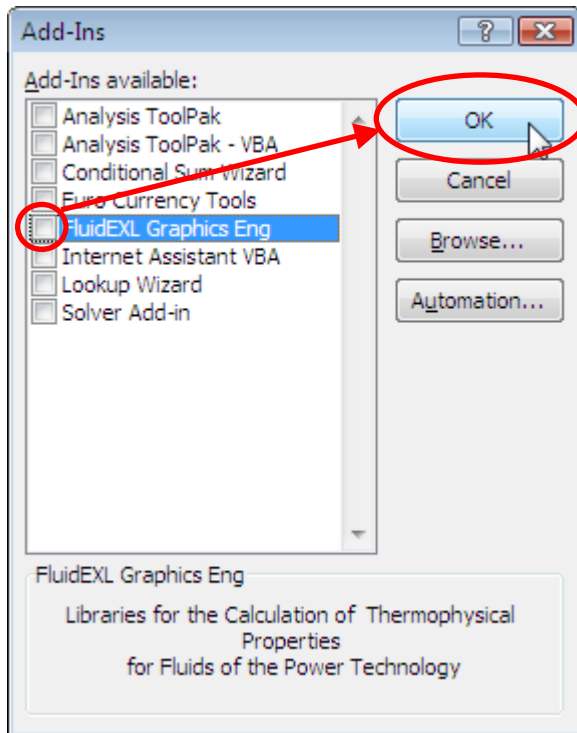


**Figure 2.37:** Dialog window "Add-Ins"

In order to remove FluidEXL *Graphics* from Windows and the hard drive, click "Start" in the Windows task bar, select "Settings" and click "Control Panel."

Now, double click on "Add or Remove Programs."

In the list box of the "Add or Remove Programs" window that appears, select

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

"FluidEXL Graphics" (for German version of Windows)

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

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

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

Answer the question of whether all shared components should be removed with "Yes to All."

Finally, close the "Add or Remove Programs" and "Control Panel" windows.

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

### 3. 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: **a\_pt\_igmix**

Subprogram with function value: **REAL\*8 FUNCTION A\_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\_A\_PT\_IGMIX(A,P,T,TYPE, COMP)**

For call from DLL: **REAL\*8 A, 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:

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:

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  $\psi_{\text{H}_2\text{O}} \geq 0.1$

**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: **cv\_pt\_igmix**

Subprogram with function value: **REAL\*8 FUNCTION CV\_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\_CV\_PT\_IGMIX(CV,P,T,TYPE, COMP)**

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 Combustion Gases)

**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  $\eta = f(p, t, \xi_1 \dots \xi_{30}$  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)<br>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)<br>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:**

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  $h = f(p, t, \xi_1 \dots \xi_{30}$  or  $\psi_1 \dots \psi_{30}$ )**

|                                 |                                                          |
|---------------------------------|----------------------------------------------------------|
| Function Name:                  | <b>h_pt_igmix</b>                                        |
| Subprogram with function value: | <b>REAL*8 FUNCTION H_PT_IGMIX(P,T,TYPE, COMP)</b>        |
| For call from FORTRAN:          | REAL*8 P, T, COMP(0:30)<br>INTEGER*4 TYPE                |
| Subprogram with parameter:      | <b>INTEGER*4 FUNCTION C_H_PT_IGMIX(H,P,T,TYPE, COMP)</b> |
| For call from DLL:              | REAL*8 H, P, T, COMP(0:30)<br>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  $\psi_{\text{H}_2\text{O}} \geq 0.1$

### 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                                                                                                       |

|                                                                                                                     |
|---------------------------------------------------------------------------------------------------------------------|
| <b>Thermal Conductivity <math>\lambda = f(p, t, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})</math></b> |
|---------------------------------------------------------------------------------------------------------------------|

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

Function Name: **M\_igmix**Subprogram with function value: **REAL\*8 FUNCTION M\_IGMIX(TYPE, COMP)**

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

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

```

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 Combustion Gases)

**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                                                                                                       |

|                                                                                                                |
|----------------------------------------------------------------------------------------------------------------|
| <b>Kinematic Viscosity <math>\nu = f(p, t, \xi_1 \dots \xi_{30} \text{ or } \psi_1 \dots \psi_{30})</math></b> |
|----------------------------------------------------------------------------------------------------------------|

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:  
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:

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

Function Name: **p\_tv\_igmix**

Subprogram with function value: **REAL\*8 FUNCTION P\_TV\_IGMIX(T,V,TYPE, COMP)**

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

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_P\_TV\_IGMIX(P,T,V,TYPE, COMP)**

```

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

```

**Input values:**

T - Temperature  $t$  in °C

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 Combustion Gases)

**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:**

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 $\xi_1 \dots \xi_{30} \neq 1$<br>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:

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

### 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: **rho\_pt\_igmix**

Subprogram with function value: **REAL\*8 FUNCTION RHO\_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\_RHO\_PT\_IGMIX\_SI(RHO,P,T,TYPE, COMP)**  
 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 Combustion Gases)

**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:**

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  $s = f(p, t, \xi_1 \dots \xi_{30}$  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)<br>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)<br>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:**

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  $\psi_{\text{H}_2\text{O}} \geq 0.1$

### 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 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  $^{\circ}\text{C}$

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:                  | <b>v_pt_igmix</b>                                        |
| Subprogram with function value: | <b>REAL*8 FUNCTION V_PT_IGMIX(P,T,TYPE, COMP)</b>        |
| For call from FORTRAN:          | REAL*8 P, T, COMP(0:30)<br>INTEGER*4 TYPE                |
| Subprogram with parameter:      | <b>INTEGER*4 FUNCTION C_V_PT_IGMIX(V,P,T,TYPE, COMP)</b> |
| For call from DLL:              | REAL*8 V, P, T, COMP(0:30)<br>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  $m^3/kg$

**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 volume  $v$  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: **w\_pt\_igmix**

Subprogram with function value: **REAL\*8 FUNCTION W\_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\_W\_PT\_IGMIX(W,P,T,TYPE, COMP)**  
 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 Combustion Gases)

**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)<br>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)<br>INTEGER*4 IGAS                       |

**Input values:**

IGAS - Gas number

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)

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 $\psi_1 \dots \psi_{30} \neq 1$<br>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. Software 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:

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 Combustion Gases)

**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  $\psi_{\text{H}_2\text{O}} \geq 0.1$

**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: **cv\_pt\_igas**

Subprogram with function value: **REAL\*8 FUNCTION CV\_PT\_IGAS(P,T,IGAS)**  
 For call from FORTRAN: REAL\*8 P,T  
 INTEGER\*4 IGAS

Subprogram with parameter: **INTEGER\*4 FUNCTION C\_CV\_PT\_IGAS(CV,P,T,IGAS)**  
 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 Combustion Gases)

**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: **INTEGER\*4 FUNCTION C\_ETA\_PT\_IGAS(ETA,P,T,IGAS)**  
 For call from DLL: 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 Combustion Gases)

**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  $\psi_{\text{H}_2\text{O}} \geq 0.1$

**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: **kappa\_pt\_igas**

Subprogram with function value: **REAL\*8 FUNCTION KAPPA\_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\_KAPPA\_PT\_IGAS(KAPPA,P,T,IGAS)**  
 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 Combustion Gases)

**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: **lambda\_pt\_igas**

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

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 [Combustion Gases](#))

### 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: **INTEGER\*4 FUNCTION C\_NY\_PT\_IGAS(NY,P,T,IGAS)**  
 For call from DLL: 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 Combustion Gases)

**Result:**

ny\_pt\_igas – Kinematic viscosity  $\nu$  in m<sup>2</sup>/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, P, 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 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:**

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

**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 |

|                                                              |
|--------------------------------------------------------------|
| <b>PRANDTL Number <math>Pr = f(p, t, \text{igas})</math></b> |
|--------------------------------------------------------------|

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: **INTEGER\*4 FUNCTION C\_PR\_PT\_IGAS(PR,P,T,IGAS)**  
 For call from DLL: 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 [Combustion Gases](#))

**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:

Specific gas constant :  $R = \sum_i (\xi_i \cdot R_i)$  or  $R = \frac{1}{\sum_i (\frac{w_i}{R_i})}$

### 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 Combustion Gases)

### 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:

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 |

|                                                               |
|---------------------------------------------------------------|
| <b>Specific Entropy <math>s = f(p, t, \text{igas})</math></b> |
|---------------------------------------------------------------|

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  $\psi_{\text{H}_2\text{O}} \geq 0.1$

**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\_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  $-73.15^{\circ}\text{C}$  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  $h = f(p, t)$

### 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 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:

Specific volume  $v$  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\*8 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 |



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

### Water and Steam

#### Library LibIF97

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

### Humid Combustion Gas Mixtures

#### Library LibHuGas

Model: Ideal mixture of the real fluids:  
 $\text{CO}_2$  - Span and Wagner     $\text{O}_2$  - Schmidt and Wagner  
 $\text{H}_2\text{O}$  - IAPWS-95    Ar - Tegeler et al.  
 $\text{N}_2$  - Span et al.  
 and of the ideal gases:  
 $\text{SO}_2$ , CO, Ne (Scientific Formulation of Bückner et al.)  
 Consideration of:  
 Dissociation from VDI 4670 and Poynting effect

### Humid Air

#### Library LibHuAir

Model: Ideal mixture of the real fluids:  

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

 Consideration of:  

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

### Carbon Dioxide Including Dry Ice

#### Library LibCO2

Formulation of Span and Wagner (1996)

### Seawater

#### Library LibSeaWa

IAPWS Industrial Formulation 2013

### Ice

#### Library LibICE

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

### Ideal Gas Mixtures

#### Library LibIdGasMix

Model: Ideal mixture of the ideal gases:  

|               |                      |               |            |
|---------------|----------------------|---------------|------------|
| Ar            | NO                   | He            | Propylene  |
| Ne            | $\text{H}_2\text{O}$ | $\text{F}_2$  | 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)

### Dry Air Including Liquid Air

#### Library LibRealAir

Formulation of Lemmon et al. (2000)

### Refrigerants

#### Ammonia

#### Library LibNH3

Formulation of Tillner-Roth et al. (1993)

#### R134a

#### Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

#### Iso-Butane

#### Library LibButane\_Iso

Formulation of Bückner and Wagner (2006)

#### n-Butane

#### Library LibButane\_n

Formulation of Bückner and Wagner (2006)

### Mixtures for Absorption Processes

#### Ammonia/Water Mixtures

#### Library LibAmWa

IAPWS Guideline 2001 of Tillner-Roth and Friend (1998)  
 Helmholtz energy equation for the mixing term (also useable for calculating Kalina Cycle)

#### Water/Lithium Bromide Mixtures

#### Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)  
 Gibbs energy equation for the mixing term

### Liquid Coolants

#### Liquid Secondary Refrigerants

#### Library LibSecRef

Liquid solutions of water with  

|                                   |                     |
|-----------------------------------|---------------------|
| $\text{C}_2\text{H}_6\text{O}_2$  | Ethylene glycol     |
| $\text{C}_3\text{H}_8\text{O}_2$  | Propylene glycol    |
| $\text{C}_2\text{H}_5\text{OH}$   | Ethyl alcohol       |
| $\text{CH}_3\text{OH}$            | Methyl alcohol      |
| $\text{C}_3\text{H}_8\text{O}_3$  | Glycerol            |
| $\text{K}_2\text{CO}_3$           | Potassium carbonate |
| $\text{CaCl}_2$                   | Calcium chloride    |
| $\text{MgCl}_2$                   | Magnesium chloride  |
| NaCl                              | Sodium chloride     |
| $\text{C}_2\text{H}_3\text{KO}_2$ | Potassium acetate   |

 Formulation of the International Institute of Refrigeration (1997)

**Ethanol****Library LibC2H5OH**

Formulation of Schroeder  
(2012)

**Methanol****Library LibCH3OH**

Formulation of  
de Reuck and Craven (1993)

**Propane****Library LibPropane**

Formulation of  
Lemmon et al. (2009)

**Siloxanes as ORC Working Fluids**

Octamethylcyclotetrasiloxane  $C_8H_{24}O_4Si_4$  **Library LibD4**

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

**Nitrogen****Library LibN2**

Formulation of  
Span et al. (2000)

**Hydrogen****Library LibH2**

Formulation of  
Leachman et al. (2009)

**Helium****Library LibHe**

Formulation of Arp et al. (1998)

**Hydrocarbons**

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

Isopentane  $C_5H_{12}$  **Library LibC5H12\_ISO**

Neopentane  $C_5H_{12}$  **Library LibC5H12\_NEO**

Isohexane  $C_6H_{14}$  **Library LibC6H14**

Toluene  $C_7H_8$  **Library LibC7H8**

Formulation of Lemmon and Span (2006)

**Further Fluids**

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

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

Hydrogen sulfide **H<sub>2</sub>S** **Library LibH2S**

Dinitrogen monoxide **N<sub>2</sub>O** **Library LibN2O**

Sulfur dioxide **SO<sub>2</sub>** **Library LibSO2**

Acetone **C<sub>3</sub>H<sub>6</sub>O** **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

**For more information please contact:**

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Professor Hans-Joachim Kretzschmar  
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02763 Zittau, Germany

Internet: [www.thermodynamics-zittau.de](http://www.thermodynamics-zittau.de)

E-mail: [hj.kretzschmar@hszg.de](mailto:hj.kretzschmar@hszg.de)

Phone: +49-3583-61-1846

Fax.: +49-3583-61-1846

**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  $Pr$

**Backward Functions**

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

**Thermodynamic Derivatives**

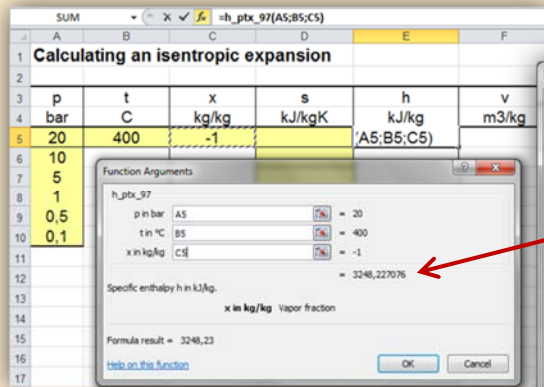
- Partial derivatives can be calculated.

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

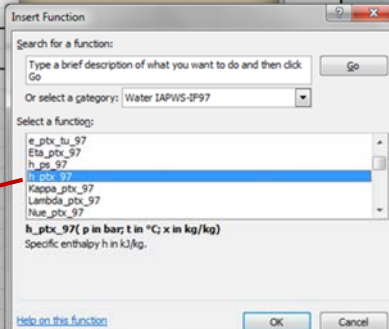


## Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

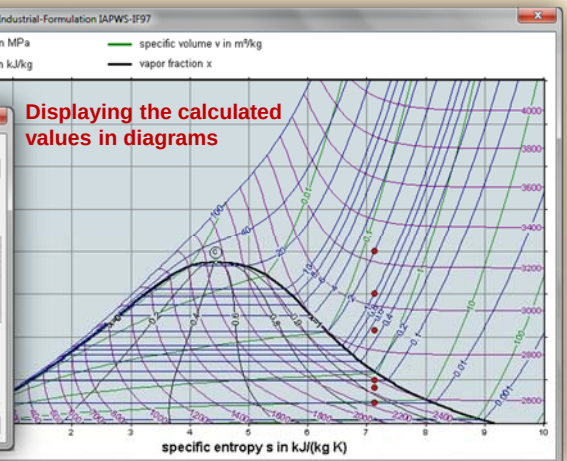
### Add-In FluidEXL<sup>Graphics</sup> for Excel<sup>®</sup>



Choosing a property library and a function



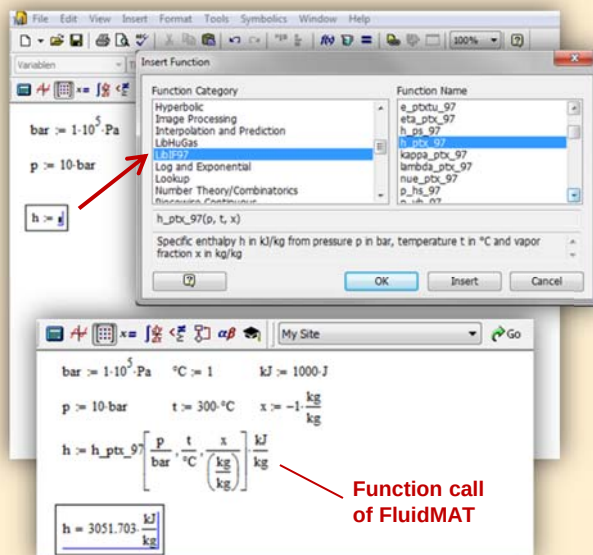
Displaying the calculated values in diagrams



Menu for the input of given property values

### Add-In FluidMAT for Mathcad<sup>®</sup>

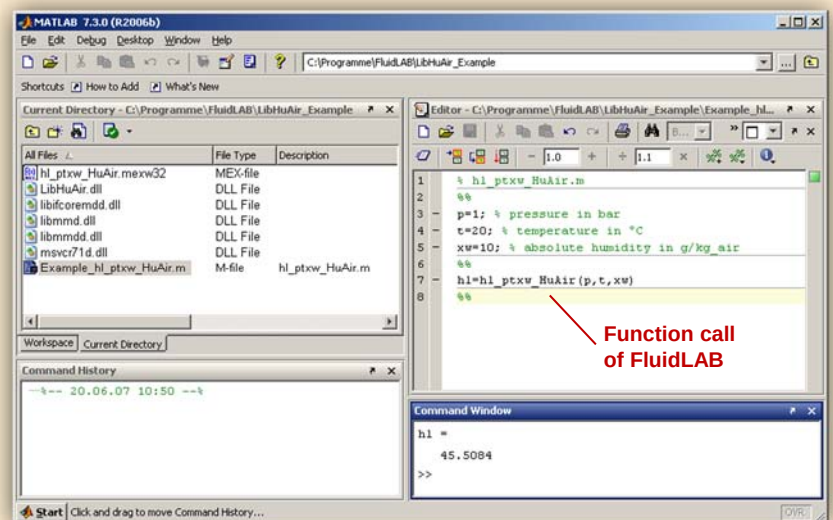
The property libraries can be used in Mathcad<sup>®</sup>.



Function call of FluidMAT

### Add-In FluidLAB for MATLAB<sup>®</sup>

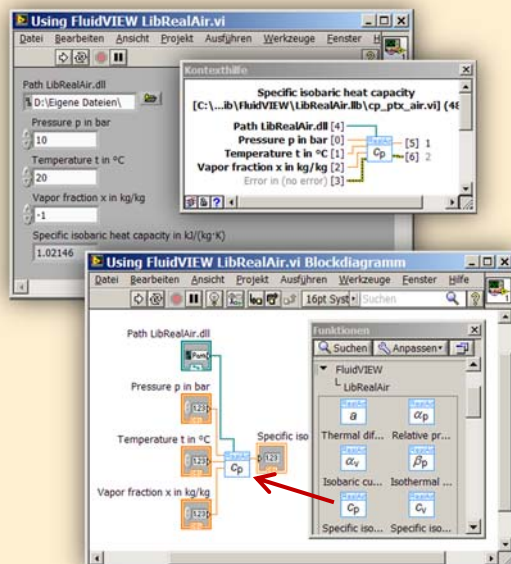
Using the Add-In FluidLAB the property functions can be called in MATLAB<sup>®</sup>.



Function call of FluidLAB

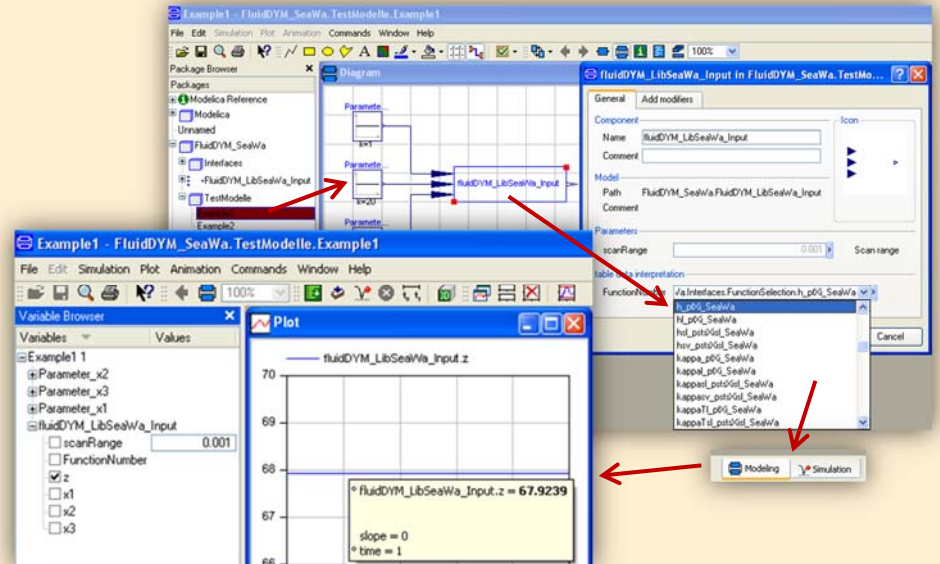
### Add-On FluidVIEW for LabVIEW<sup>®</sup>

The property functions can be calculated in LabVIEW<sup>®</sup>.

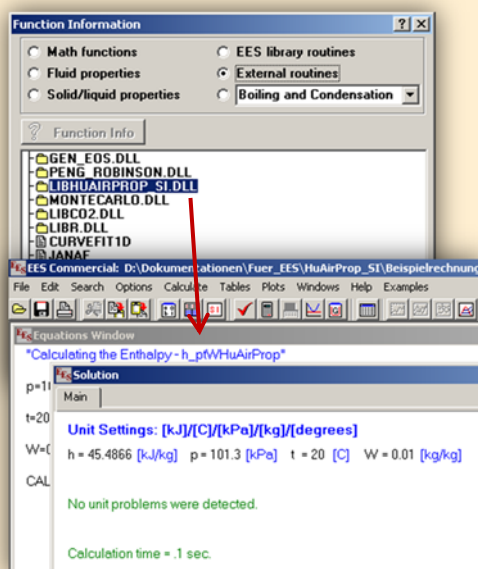


### Add-In FluidDYM for DYMOLA<sup>®</sup> (Modelica) and SimulationX<sup>®</sup>

The property functions can be called in DYMOLA<sup>®</sup> and SimulationX<sup>®</sup>.



## Add-In FluidEES for Engineering Equation Solver®



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



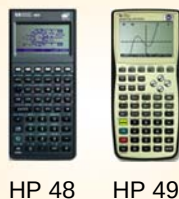
## Online Property Calculator at [www.thermodynamics-zittau.de](http://www.thermodynamics-zittau.de)

## Property Software for Pocket Calculators

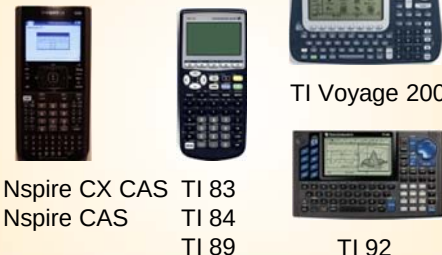
### FluidCasio



### FluidHP



### FluidTI



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Internet: [www.thermodynamics-zittau.de](http://www.thermodynamics-zittau.de)  
Phone: +49-3583-61-1846  
Fax: +49-3583-61-1846

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  $Pr$

### Backward Functions

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

### Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

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## 7. Satisfied Customers

Date: 04/2014

The following companies and institutions use the property libraries

- FluidEXL *Graphics* for Excel®
- FluidLAB for MATLAB®
- FluidMAT for Mathcad®
- FluidEES for Engineering Equation Solver® EES
- FluidDYM for Dymola® (Modelica) and SimulationX®
- FluidVIEW for LabVIEW®:

### 2014

|                                                |         |
|------------------------------------------------|---------|
| 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 Nurnberg               | 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<br>for RWE Essen             | 02/2014 |
| Technical University of Prague, Czech Republic | 02/2014 |
| HS Augsburg                                    | 02/2014 |
| Envi-con, Nürnberg                             | 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<br>for RWE Essen           | 08/2013, 11/2013<br>12/2013 |
| University of Budapest, Hungary              | 08/2013                     |
| Siemens, Frankenthal                         | 08/2013, 10/2013<br>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                     |

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|--------------------------------------------------|------------------|
| Schwing/Stetter GmbH, Memmingen                  | 05/2013          |
| Vattenfall, Berlin                               | 05/2013          |
| AUTARK, Kleinmachnow                             | 05/2013          |
| STEAG, Zwingenberg                               | 05/2013          |
| Hochtief, Düsseldorf                             | 05/2013          |
| University of Stuttgart                          | 04/2013          |
| Technical University -Bundeswehr, Munich         | 04/2013          |
| Rerum Cognitio Forschungszentrum, Frankfurt      | 04/2013          |
| Kältetechnik Dresden + 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 Ingenieurbüro, 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

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|------------------------------------------|------------------|
| 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          |

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|-----------------------------------------------------------------|------------------|
| 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<br>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<br>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)<br>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          |

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|----------------------------------|------------------|
| 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 |

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|-----------------------------------------------------|--------------------------------------|
| Weihenstephan University of Applied Sciences        | 07/2011, 09/2011<br>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,<br>08/2011         |
| Salzgitter Flachstahl, Salzgitter                   | 05/2011                              |
| Helbling Beratung & Bauplanung, Zurich, Switzerland | 05/2011                              |
| INEOS, Cologne                                      | 04/2011                              |
| Enseleit Consulting Engineers, Siebigerode          | 04/2011                              |
| Witt Consulting Engineers, Stade                    | 03/2011                              |
| Helbling, Zurich, Switzerland                       | 03/2011                              |
| MAN Diesel, Copenhagen, Denmark                     | 03/2011                              |
| AGO, Kulmbach                                       | 03/2011                              |
| University of Duisburg                              | 03/2011, 06/2011                     |
| CCP, Marburg                                        | 03/2011                              |
| BASF, Ludwigshafen                                  | 02/2011                              |
| ALSTOM Power, Baden, Switzerland                    | 02/2011                              |
| Universität der Bundeswehr, Munich                  | 02/2011                              |
| Calorifer, Elgg, Switzerland                        | 01/2011                              |
| STRABAG, Vienna, Austria                            | 01/2011                              |
| TUEV Sued, Munich                                   | 01/2011                              |
| ILK Dresden                                         | 01/2011                              |
| Technical University of Dresden                     | 01/2011, 05/2011<br>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 |

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|------------------------------------------------------------------|-----------------------------|
| 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<br>10/2010 |
| Hot Rock, Karlsruhe                                              | 05/2010                     |
| Darmstadt University of Applied Sciences                         | 05/2010                     |
| Voith, Heidenheim                                                | 04/2010                     |
| CombTec, Zittau                                                  | 04/2010                     |

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|-------------------------------------------------------------|------------------|
| 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<br>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                     |

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|----------------------------------------------------------|------------------|
| 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          |
| <b>2008</b>                                              |                  |
| 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          |

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|-----------------------------------------------------------------------------------------|------------------|
| 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,<br>Professorship of Building Services                  | 07/2008          |
| Technical University of Cottbus,<br>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          |
| Poyry, Dresden                                                                          | 09/2008          |
| WINGAS, Kassel                                                                          | 09/2008          |
| TUEV Sued, Dresden                                                                      | 10/2008          |
| Technical University of Dresden,<br>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 |

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|---------------------------------------------------------------------------------|------------------|
| 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,<br>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,<br>Department of Engineering Sciences | 10/2007          |
| Endress+Hauser Messtechnik, Hannover                                            | 11/2007          |
| Munich University of Applied Sciences,<br>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, Bochoy, 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,<br>Department of Mechanical Engineering and Mechatronics | 02/2006          |
| University of Stuttgart,<br>Department of Thermal Fluid Flow Engines                                | 02/2006          |

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|--------------------------------------------------------------------------------------------|------------------|
| Technical University of Munich,<br>Chair in Apparatus and Plant Engineering                | 02/2006          |
| Energietechnik Leipzig (company license),                                                  | 02/2006          |
| Siemens Power Generation, Erlangen                                                         | 02/2006, 03/2006 |
| RWE Power, Essen                                                                           | 03/2006          |
| WAETAS, Poberschau                                                                         | 04/2006          |
| Siemens Power Generation, Goerlitz                                                         | 04/2006          |
| Technical University of Braunschweig,<br>Department of Thermodynamics                      | 04/2006          |
| EnviCon & Plant Engineering, Nuremberg                                                     | 04/2006          |
| Brassel Engineering, Dresden                                                               | 05/2006          |
| University of Halle-Merseburg,<br>Department of USET Merseburg incorporated society        | 05/2006          |
| Technical University of Dresden,<br>Professorship of Thermic Energy Machines and Plants    | 05/2006          |
| Fichtner Consulting & IT Stuttgart<br>(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,<br>Course of Studies Construction and Development | 10/2006          |
| Siemens Power Generation, Duisburg                                                         | 10/2006          |
| Hannover University of Applied Sciences,<br>Department of Mechanical Engineering           | 10/2006          |
| Siemens Power Generation, Berlin                                                           | 11/2006          |
| Zikesch Armaturentechnik, Essen                                                            | 11/2006          |
| Wismar University of Applied Sciences, Seafaring Department                                | 11/2006          |
| BASF, Schwarzheide                                                                         | 12/2006          |
| Enertech Energie und Technik, Radebeul                                                     | 12/2006          |

## 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<br>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,<br>Department of Mechanical Engineering and Process Engineering | 05/2005                     |
| Redacom, Nidau, Switzerland                                                                                 | 06/2005                     |
| Dumas Verfahrenstechnik, Hofheim                                                                            | 06/2005                     |
| Alensys Engineering, Erkner                                                                                 | 07/2005                     |
| Stadtwerke Leipzig                                                                                          | 07/2005                     |
| SaarEnergie, Saarbruecken                                                                                   | 07/2005                     |
| 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,<br>Department of Mechanical Engineering, Switzerland                  | 10/2005                     |
| 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 |

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|-----------------------------------------------------------------------------------------|------------------|
| Ulm University of Applied Sciences                                                      | 03/2004          |
| Visteon, Kerpen                                                                         | 03/2004, 10/2004 |
| Technical University of Dresden,<br>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          |

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|----------------------------------------------------------------------------|---------|
| 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,<br>Department of Supply Engineering | 12/2003 |
| SorTech, Freiburg                                                          | 12/2003 |
| Mainova, Frankfurt                                                         | 12/2003 |
| Energieversorgung Halle                                                    | 12/2003 |

## 2002

|                                                                                    |         |
|------------------------------------------------------------------------------------|---------|
| Hamilton Medical AG, Rhaezuens, Switzerland                                        | 01/2002 |
| Bochum University of Applied Sciences,<br>Department of Thermo- and Fluid Dynamics | 01/2002 |
| SAAS, Possendorf/Dresden                                                           | 02/2002 |
| Siemens, Karlsruhe<br>(general license for the WinIS information system)           | 02/2002 |
| 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<br>(general EBSILON program license)                        | 06/2002 |
| 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<br>(company licenses and distribution)      | 08/2002 |
| 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<br>(general license and training test benches) | 12/2002 |
| VEAG, Berlin (group license)                                                    | 12/2002 |

## 2001

|                                                                              |                             |
|------------------------------------------------------------------------------|-----------------------------|
| ALSTOM Power, Baden, Switzerland                                             | 01/2001, 06/2001<br>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<br>Power Machinery and Plants | 02/2001                     |
| PREUSSAG NOELL, Wuerzburg                                                    | 03/2001                     |
| Fichtner Consulting & IT Stuttgart<br>(company licenses and distribution)    | 04/2001                     |
| Muenstermann GmbH, Telgte-Westbevern                                         | 05/2001                     |
| SaarEnergie, Saarbruecken                                                    | 05/2001                     |

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|--------------------------------------------------------------------------|---------|
| Siemens, Karlsruhe<br>(general license for the WinIS information system) | 08/2001 |
| Neusiedler AG, Ulmerfeld, Austria                                        | 09/2001 |
| h s energieanlagen, Freising                                             | 09/2001 |
| Electrowatt-EKONO, Zurich, Switzerland                                   | 09/2001 |
| IPM Zittau/Goerlitz University of Applied Sciences (general license)     | 10/2001 |
| eta Energieberatung, Pfaffenhofen                                        | 11/2001 |
| ALSTOM Power Baden, Switzerland                                          | 12/2001 |
| VEAG, Berlin (group license)                                             | 12/2001 |

## 2000

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

## 1999

|                                   |         |
|-----------------------------------|---------|
| Bayernwerk, Munich                | 01/1999 |
| DREWAG, Dresden (company license) | 02/1999 |
| KEMA IEV, Dresden                 | 03/1999 |

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|----------------------------------------------------------------------------|---------|
| Regensburg University of Applied Sciences                                  | 04/1999 |
| Fichtner Consulting & IT, Stuttgart<br>(company licenses and distribution) | 07/1999 |
| 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<br>(general KPRO program license) | 05/1998 |
| 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**

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