KCE
ThermoFluidProperties

Property Library for Ammonia

FluidMAT with LibNH3 for Mathcad®

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Software for the Calculation of the Properties of Ammonia

FluidMAT
LibNH3

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0 Package Contents

Zip-file "CD_FluidMAT_LibNH3.zip" includes the following files:

FluidMAT_LibNH3_Setup.exe	- Self-extracting and self-installing program
LibNH3.dll	- DLL with functions of the LibNH3 library
FluidMAT_LibNH3_Docu.pdf	- User's Guide

1. Property Functions

Functional Dependance	Function Name	Call from Fortran-Program	Call from DLL LibNH3 as Parameter	Property or Function	Unit of the Result
$a = f(p,t,x)$	a_ptx_NH3	A_PTX_NH3(P,T,X)	C_A_PTX_NH3(A,P,T,X)	Thermal diffusivity	m^2/s
$c_p = f(p,t,x)$	cp_ptx_NH3	CP_PTX_NH3(P,T, X)	C_CP_PTX_NH3(CP,P,T,X)	Specific isobaric heat capacity	kJ/(kg K)
$c_v = f(p,t,x)$	cv_ptx_NH3	CV_PTX_NH3(P,T, X)	C_CV_PTX_NH3(CV,P,T,X)	Specific isochoric heat capacity	kJ/(kg K)
$\eta = f(p,t,x)$	eta_ptx_NH3	ETA_PTX_NH3(P,T	C_ETA_PTX_NH3(ETA,P,T,X)	Dynamic viscosity	Pa s
$h = f(p,t,x)$	h_ptx_NH3	H_PTX_NH3(P,T,X	C_H_PTX_NH3(H,P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p,t,x)$	kappa_ptx_NH3	KAP_PTX_NH3(P,	C_KAP_PTX_NH3(KAP,P,T,X)	Isentropic exponent	-
$\lambda = f(p,t,x)$	lambda_ptx_NH3	LAM_PTX_NH3(P,	C_LAM_PTX_NH3(LAM,P,T,X)	Thermal conductivity	W/(m K)
$\nu = f(p,t,x)$	ny_ptx_NH3	NY_PTX_NH3(P,T,X)	C_NY_PTX_NH3(NY,P,T,X)	Kinematic viscosity	m^2/s
$p_s = f(t)$	ps_t_NH3	PS_T_NH3(T)	C_PS_T_NH3(PS,T)	Saturation pressure	bar
$Pr = f(p,t,x)$	Pr_ptx_NH3	PR_PTX_NH3(P,T,	C_PR _PTX_NH3(PR,P,T,X)	*Prandtl*-number	-
$\rho = f(p,t,x)$	rho_ptx_NH3	RHO_PTX_NH3(P,	C_RHO_PTX_NH3(RHO,P,T,X)	Density	kg/m^3
$s = f(p,t,x)$	s_ptx_NH3	S_PTX_NH3(P,T,X)	C_S_PTX_NH3(S,P,T,X)	Specific entropy	kJ/(kg K)
$t = f(p,h)$	t_ph_NH3	T_PH_NH3(P,H)	C_T_PH_NH3(T,P,H)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p,s)$	t_ps_NH3	T_PS_NH3(P,S)	C_T_PS_NH3(T,P,S)	Backward function: Temperature from pressure and entropy	°C
$t_s = f(p)$	ts_p_NH3	TS_P_NH3(P)	C_TS_P_NH3(TS,P)	Saturation temperature	°C
$u = f(p,t,x)$	u_ptx_NH3	U_PTX_NH3(P,T,X	C_U_PTX_NH3(U,P,T,X)	Specific internal energy	kJ/kg
$v = f(p,t,x)$	v_ptx_NH3	V_PTX_NH3(P,T,X)	C_V_PTX_NH3(V,P,T,X)	Specific volume	m^3/kg

Functional Dependance	Function Name	Call from Fortran-Program	Call from DLL LibNH3 as Parameter	Property or Function	Unit of the Result
$w = f(p,t,x)$	w_ptx_NH3	W_PTX_NH3(P,T,X	C_W_PTX_NH3(W,P,T,X)	Isentropic speed of sound	m/s
$x = f(p,h)$	x_ph_NH3	X_PH_NH3(P,H)	C_X_PH_NH3(X,P,H)	Backward function: Vapor fraction from pressure and enthalpy	kg/kg
$x = f(p,s)$	x_ps_NH3	X_PS_NH3(P,S)	C_X_PS_NH3(X,P,S)	Backward function: Vapor fraction from pressure and entropy	kg/kg

Units: t in °C
p in bar
x in kg saturated steam/kg wet steam

Range of Validity:

Temperature: from - 77.65 °C to 446.85 °C
Pressure: from 0.0609422 bar to 10000 bar

Reference state:

Saturated liquid t = 0 °C
$h = h'(t = 0\ °C) = 200$ kJ/kg, $s = s'(t = 0\ °C) = 1$ kJ/(kg K)

Details on the vapor fraction *x*:

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction *x* are to be considered:

Single-phase region

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) x = –1 must be entered as a pro-forma value.

Wet-steam region

If the state point to be calculated is located in the wet steam region, a value for *x* between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for *x*. When calculating wet steam either the given value for *t* and p = -1000 or the given value for *p* and t = -1000 and in both cases the value for *x* between 0 and 1 must be entered.

If *p* and *t* and *x* are entered as given values, the program considers *p* and *t* to be appropriate to represent the vapor pressure curve. If this is not the case the calculation for the property of the chosen function results in –1000.

Wet steam region: Temperature ranges from t = - 77.65°C to t_c = 132.36°C

Pressure ranges from p = 0.0609422 bar to p_c = 113.6114 bar

Note:

If the calculation results in –1000, the values entered represent a state point beyond the range of validity of LibNH3. For further information on each function and its range of validity see Chapter 3. The same information may also be accessed via the online help pages.

2 Application of FluidMAT in Mathcad®

FluidMAT has been developed to calculate thermodynamic properties in Mathcad® more conveniently. Within Mathcad, it enables the direct call of functions relating to ammonia from the LibNH3 property library.

2.1 Installing FluidMAT

In this section, the installation of FluidMAT LibNH3 is described.

Before you begin, it is best to close any Windows® applications, since Windows may need to be rebooted during the installation process.

After you have downloaded and extracted the zip-file "CD_FluidMAT_LibNH3_Eng.zip", you will see the folder

CD_FluidMAT_LibNH3_Eng (for English version of Windows)
CD_FluidMAT_LibNH3 (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:

FluidMAT_LibNH3_Docu_Eng.pdf
FluidMAT_LibNH3_Setup.exe
LibNH3.dll.

In order to run the installation of FluidMAT including the LibNH3 property library double-click the file

FluidMAT_LibNH3_Setup.exe.

Installation may start with a window noting that all Windows programs should be closed.

When this is the case, the installation can be continued. Click the "Next >" button.

Now, you will be informed on the FluidMAT product in the "ReadMe-File" window. Click "Next >" to leave this window.

In the following dialog box, "Choose Destination Location" (see following figure), the default path where Mathcad has been installed will be shown

C:\Program Files\Mathcad\Mathcad 14\ (for English version of Windows)
C:\Programme\Mathcad\Mathcad 14\ (for German version of Windows).

By clicking the "Browse…" button, you can change the installation directory before installation.

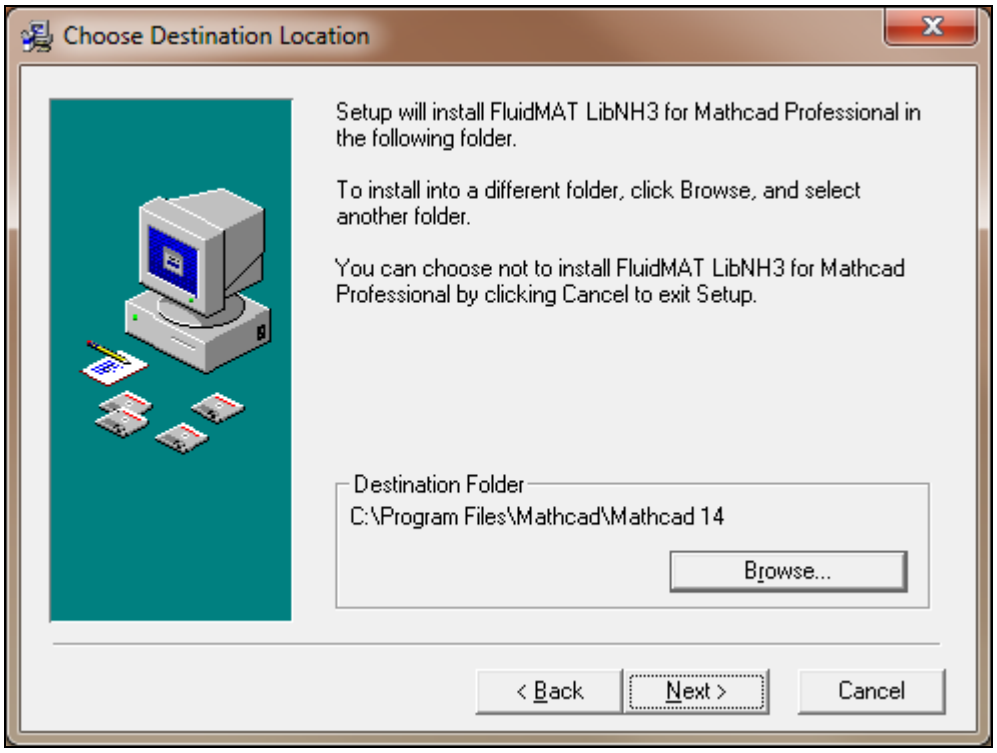

Figure 2.1: "Choose Destination Location" dialog window

The path will be displayed in the window.

Click on "Next >" in the window "Choose Destination Location".

Click on the "Next >" button in the "Start Installation" window.

After FluidMAT LibNH3 has been installed, the sentence "FluidMAT LibNH3 for Mathcad Professional has been successfully installed" will be shown.

Confirm this by clicking the "Finish >" button.

During the installation process the following files have been copied into the chosen destination folder (which is the folder, where Mathcad was installed):

advapi32.dll	Dynamic link library for use in Windows® programs
Dforrt.dll	Dynamic link library for use in Windows programs
Dformd.dll	Dynamic link library for use in Windows programs
LC.dll	Dynamic link library for use in Windows programs
LibNH3.dll	Property library for water and steam
msvcp60.dll	Dynamic link library for use in Windows programs
Msvcrt.dll	Dynamic link library for use in Windows programs
Readme.txt	ReadMe file
INSTALL_MAT_LibNH3.LOG	Installation log-file

The following files were installed into your Mathcad subdirectory \userEFI:

MAT_LibNH3.dll	Function definition of LibNH3

The following files were installed into your Mathcad subdirectory \doc\funcdoc:

MAT_LibNH3_DE.xml	Function registration in the dialog window "Insert Function" for LibNH3 (German Mathcad version 12 or higher)
MAT_LibNH3_EN.xml	Function registration in the dialog window "Insert Function" for LibNH3 (English Mathcad version 12 or higher)
MAT_LibNH3.xml	Function registration in the dialog window "Insert Function" for LibNH3 (Mathcad version 11 or lower)

Now, you have to overwrite the file "LibNH3.dll" in your Mathcad directory with the file of the same name provided on your CD with FluidMAT.
To do this, open the CD in "My Computer" and click on the file "LibNH3.dll" in order to highlight it. Then click on the "Edit" menu in your Explorer and select "Copy". Now, open your Mathcad directory (the standard being

C:\Program Files\Mathcad\Mathcad 14 (for English version of Windows)
C:\Programme\Mathcad\Mathcad 14 (for German version of Windows))

and insert the file "LibNH3.dll" by clicking the "Edit" menu in your Explorer and then select "Paste". Answer the question whether you want to replace the file by clicking the "Yes" button.
You have overwritten the file "LibNH3.dll" successfully.

From within Mathcad you can now select the FluidMAT LibNH3 property functions.

2.2 Licensing the LibNH3 Property Library

The licensing procedure has to be carried out when you are calculating a function with LibNH3 in Mathcad® and a FluidMAT prompt message appears. In this case, you will see the "License Information" window for LibNH3 (see Figure 2.2).

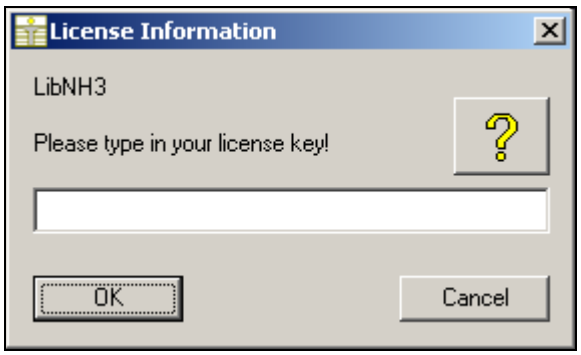

Figure 2.2: "License Information" window

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:

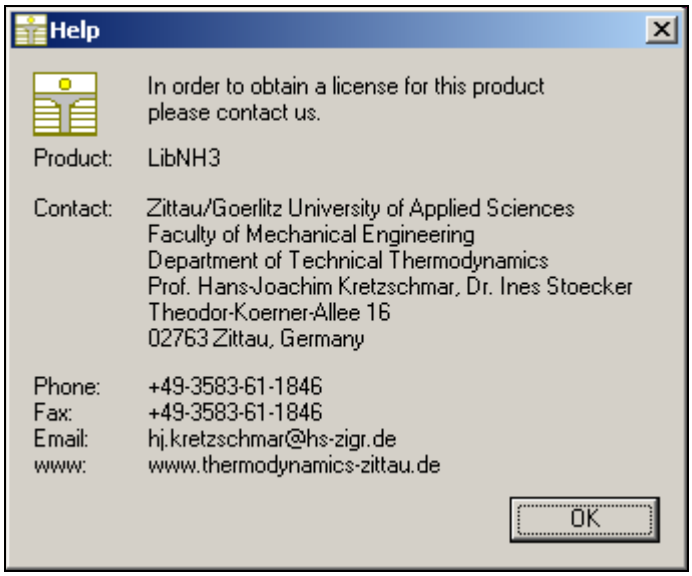

Figure 2.3: "Help" window

If you do not enter a valid license it is still possible to use Mathcad by clicking "Cancel". In this case, the LibNH3 property library will display the result "–11111111" for every calculation.
The "License Information" window will appear every time you use the LibNH3 property library in Mathcad unless you uninstall FluidMAT according to the description in section 2.3 of this User's Guide.
Should you not wish to license the LibNH3 property library, you have to delete the files

LibNH3.dll
MAT_LibNH3.dll
MAT_LibNH3.xml
MAT_LibNH3_DE.xml
MAT_LibNH3_EN.xml

in the installation folder of FluidMAT (the standard being

C:\Program Files\Mathcad\Mathcad 14 (for English version of Windows)
C:\Programme\Mathcad\Mathcad 14 (for German version of Windows)

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

2.3 Example: Calculation of the Enthalpy *h* = f(*p*,*t*,*x*)

Now we will calculate, step by step, the specific enthalpy *h* as a function of pressure *p*, temperature *t* and vapor fraction *x* for ammonia, using FluidMAT.

Please carry out the following instructions:

- Start Mathcad.
- Type "p:" and enter the value for the pressure *p* in bar.
  (Range of validity of LibNH3: *p* = 0.0609422 bar... 10000 bar)
  e. g.: Enter "p:1" for the first operand
- Type "t:" and enter the value for the temperature *t* in °C.
  (Range of validity of LibNH3: *t* = -77.65 °C ... 446.85 °C)
  e. g.: Enter "t:-30" for the second operand
- Type "x:" and enter the value for the vapor fraction *x* in $kg_{sat.\ steam}$ / $kg_{wet\ steam.}$
  Since the wet steam region is calculated automatically by the subprograms, the following fixed details on the vapor fraction *x* are to be considered when the value for *x* is entered:

  Single-phase region

  If the state point to be calculated is located in the single-phase region (liquid or superheated steam) x = –1 must be entered as a pro-forma value.
  Here the backward functions will also result in x = –1.

  Wet-steam region

  When calculating wet steam, a value between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for *x*. It is adequate to enter either the given value for *t* and p = –1000, or the given value for *p* and t = –1000, plus the value for *x* between 0 and 1. When p and t and x are entered as given values, the program will consider *p* and *t* to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the property of the chosen function to be calculated results in –1000.

  (NH3 saturation line: t_t = -77.65 °C ... t_c = 132.36 °C
  p_t = 0.0609422 bar ... p_c = 113.6114 bar)

  e. g.: Enter "x:-1" for the third operand
- Confirm your entry by pressing the "ENTER" key.
- Your Mathcad calculation window should look like Figure 2.4:

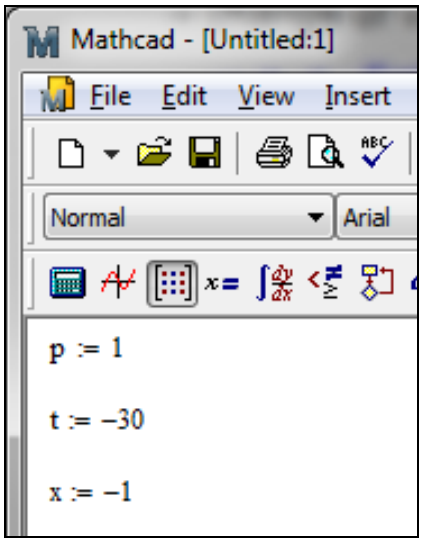

Figure 2.4: Example Mathcad® sheet after input of the given parameters

- Now, type "h:" in the Mathcad window. Now, you will see **h : = ■** .
- Click on "Insert" in the upper menu bar and then click "Function…". Now, the "Insert function" window appears (see next figure).

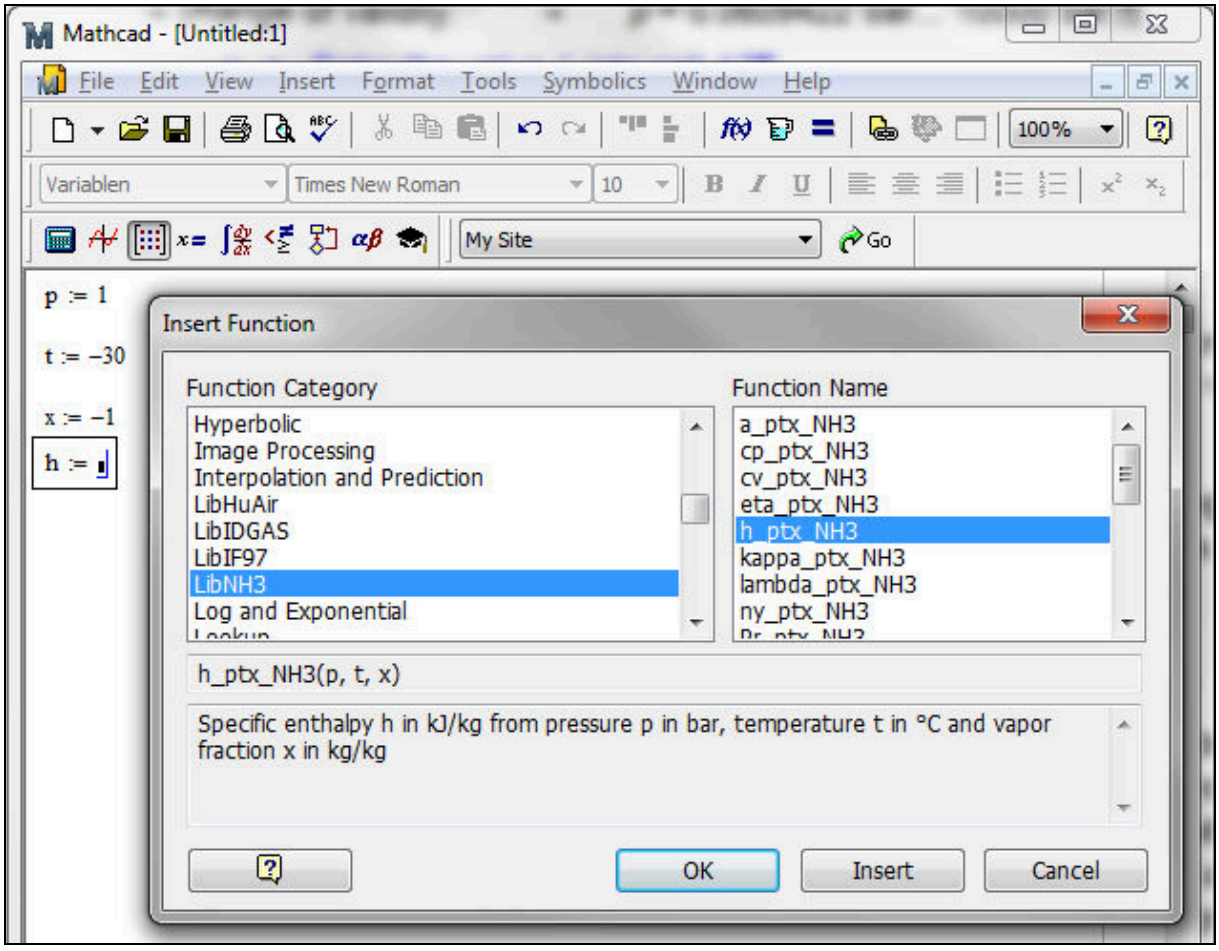

Figure 2.5: Choice of library and function name

- Search and click the "LibNH3" library under "Function Category" in the left part of the window.

- Now, search and click the "h_ptx_NH3" function under "Function Name" on the right hand side of the window.

  The function category and the function name will be inverted, highlighted and furthermore the description of the function and the measuring units of the variables are shown.

- Now, click "OK" and you will see **h : = h_ptx_NH3 (■ , ■ , ■)** in the Mathcad window (see next figure).

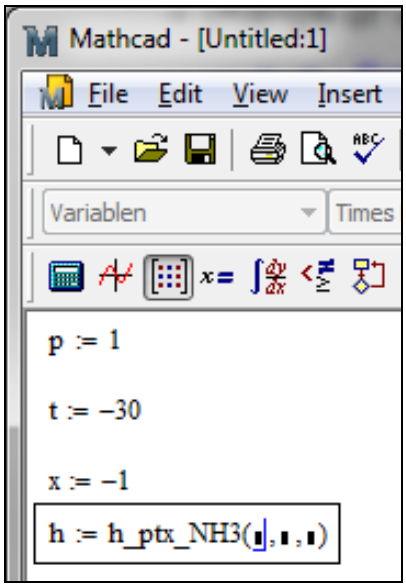

Figure 2.6: Example Mathcad® sheet with formula and placeholders

- The cursor is now situated on the first operand. You can now enter the value for *p* either by entering the value directly or by entering the name of the variable where the value was saved.

  ⇒ e.g.: Enter "p".

- Situate the cursor on the next placeholder. You can now enter the value for the temperature *t* either by entering the value for *t* directly or by typing the name of the variable in which the value of the temperature has been saved.

  ⇒ e.g.: Enter "t".

- Situate the cursor on the next placeholder. You can now enter the value for the humidity ratio *x* either by entering the value for *x* directly or by typing the name of the variable in which the value of the humidity ratio has been saved.

  ⇒ e.g.: Enter "x".

- Close the input formula by pressing the "Enter"-Key.
- Your Mathcad calculation window should like the following figure:

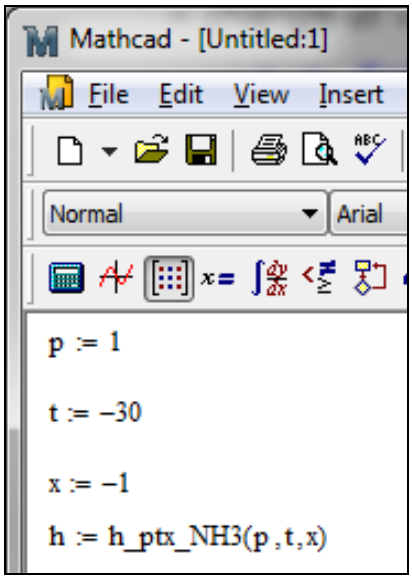

Figure 2.7: Example Mathcad® sheet with formula and variables

- You can now go on working with the variable *h* which we have just calculated.
- If you wish to see the result, you have to type the following command on the next line in the Mathcad window:
  "h =".

  You will now see the result h=1.426 x 10^3 .

The representation of the result depends on the amount of places and decimal places which you have set before. In the next figure you can see that we have chosen the decimal number format and the amount of four decimal places.

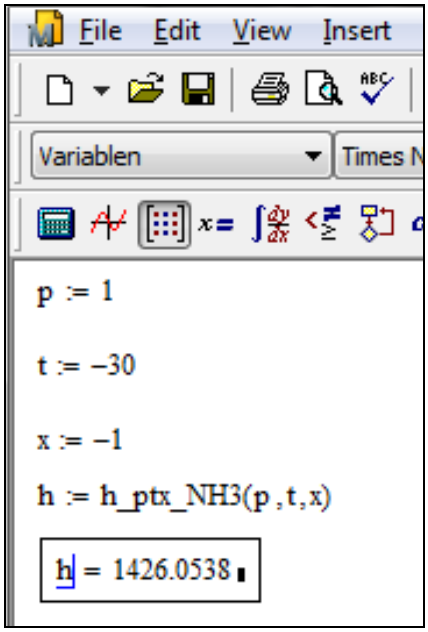

Figure 2.8: Example Mathcad® sheet with finished calculation

2.4 Example: Calculation of the Enthalpy *s* = f(*p*,*t*,*x*)

Now, we will calculate the specific entropy s = f(*p*,*t*,*x*) from the same values of *p*, *t* and *x*:

- Your Mathcad calculation window should like Figure 2.4:

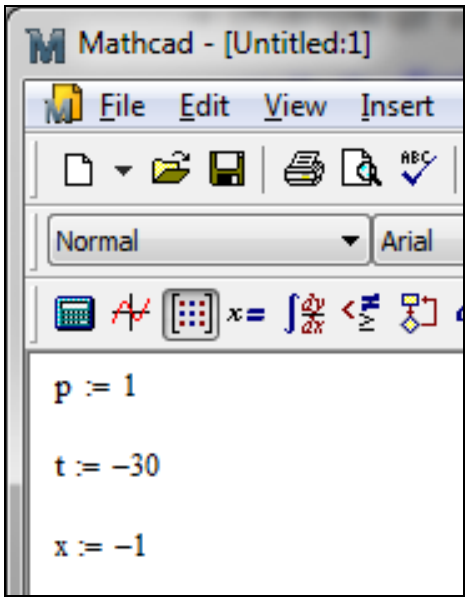

Figure 2.9: Example Mathcad® sheet after input of the given parameters

- Now, type "s:" in the Mathcad window. Now, you will see **s : =** ■ .
- Click on "Insert" in the upper menu bar and then click "Function…". Now, the "Insert function" window appears (see Figure 2.10).

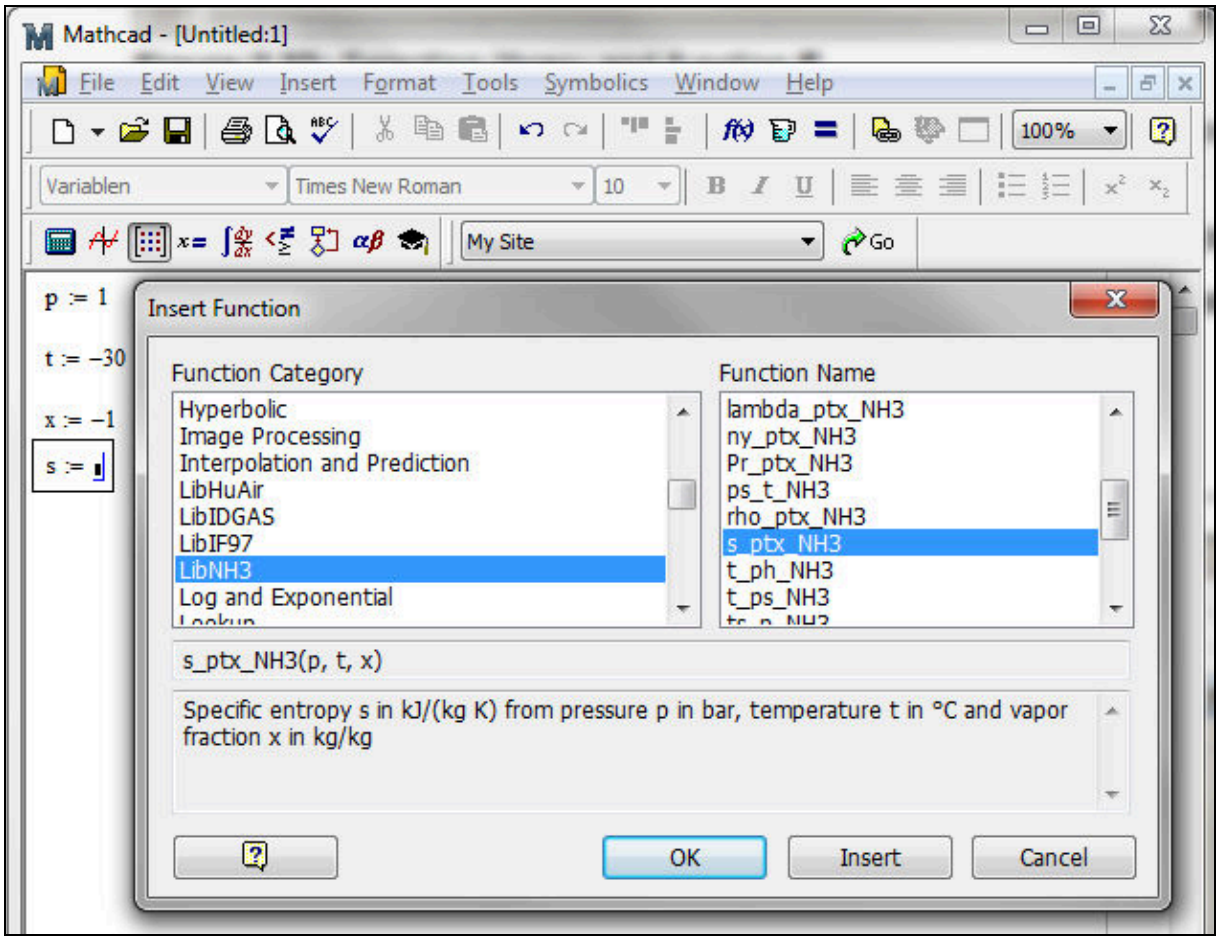

Figure 2.10: Choice of library and function name

- Search and click the "LibNH3" library under "Function Category" in the left part of the window.
- Now, search and click the "s_ptx_NH3" function under "Function Name" on the right hand side of the window.

  The function category and the function name will be inverted, highlighted and furthermore the description of the function and the measuring units of the variables are shown.
- Now, click "OK" and you will see **s : = s_ptx_NH3 (■ , ■ , ■)** in the Mathcad window (see Figure 2.11).

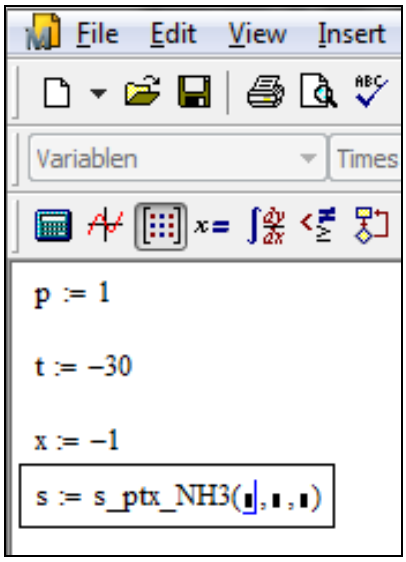

Figure 2.11: Example Mathcad® sheet with formula and placeholders

- The cursor is now situated on the first operand. You can now enter the value for *p* either by entering the value directly or by entering the name of the variable where the value was saved.

  ⇒ e.g.: Enter "p".

- Situate the cursor on the next placeholder. You can now enter the value for the temperature *t* either by entering the value for *t* directly or by typing the name of the variable in which the value of the temperature has been saved.

  ⇒ e.g.: Enter "t".

- Situate the cursor on the next placeholder. You can now enter the value for the humidity ratio *x* either by entering the value for *x* directly or by typing the name of the variable in which the value of the humidity ratio has been saved.

  ⇒ e.g.: Enter "x".

- Close the input formula by pressing the "Enter"-Key.
- Your Mathcad calculation window should look like the following figure:

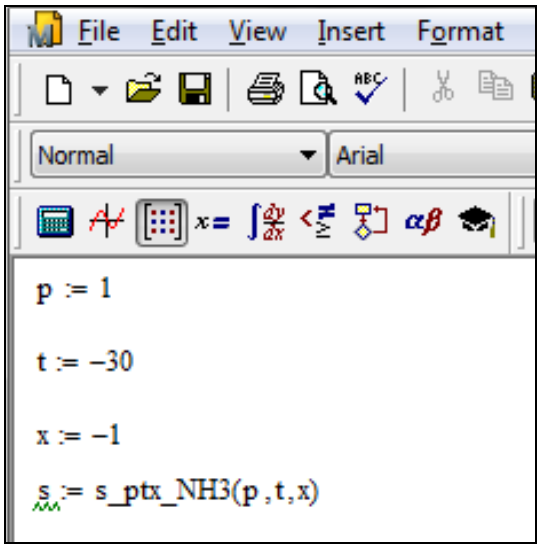

Figure 2.12: Example Mathcad® sheet with formula and variables

- You can now go on working with the variable *s* which we have just calculated.
- If you wish to see the result, you have to type the following command on the next line in the Mathcad window:
  "s =".

  You will now see the result s = 6.161.

The representation of the result depends on the amount of places and decimal places which you have set before. In the next figure you can see that we have chosen the decimal number format and the amount of four decimal places.

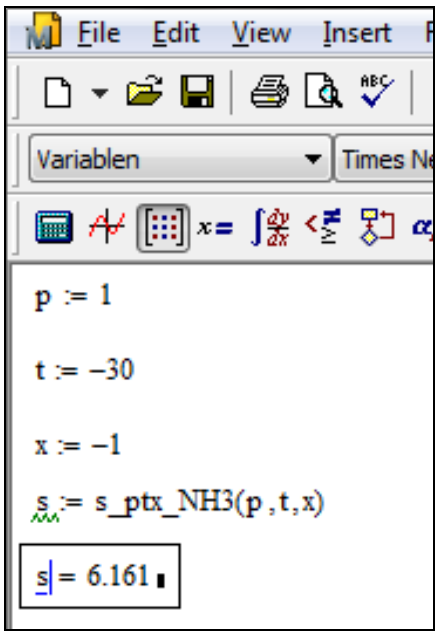

Figure 2.8: Example Mathcad® sheet with finished calculation

2.5 Removing FluidMAT

To remove FluidMAT from Mathcad® and from your hard drive, carry out the following steps:

- Click "Start" in the lower task bar of your desktop, then "Settings" and then "Control Panel".
- Now, double click on "Add or Remove Programs".
- In the list box of the "Add or Remove Programs" window that appears select "FluidMAT LibNH3 for Mathcad Professional" 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.
- Finally, close the "Add or Remove Programs" and "Control Panel" windows.

Now FluidMAT has been removed.

3. Program Documentation

Thermal Diffusivity a = f(p,t,x)

Function Name:	**a_ptx_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION A_PTX_NH3(P,T,X)** REAL*8 P,T,X
Subprogram with Parameter: for call from DLL	**INTEGER*4 FUNCTION C_A_PTX_NH3(A,P,T,X)** REAL*8 A,P,T,X

Input Values

P - Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

A_PTX_NH3, **A** or **a_ptx_NH3** - Thermal diffusivity $a = \frac{\lambda * v}{c_p}$ in m² / s

Range of validity

Temperature range:	from – 65.0 °C to 400.0 °C
Pressure range:	from 0.0609422 bar to 800 bar

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction *x* are to be considered:

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) x = –1 must be entered as a pro-forma value.

If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered. The calculation for x-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and p = -1000, or the given value for p and t = -1000, plus the value for x (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Saturated liquid and vapor line:	Temperature ranges from t_t = - 65.0 °C to t_c = 132.36 °C Pressure ranges from p_t = 0.0609422 bar to p_c = 113.6114 bar

Results for wrong input values

Result **A_PTX_NH3, A = - 1000** or **a_ptx_NH3 = - 1000** for input values:

Single-phase region: (x = - 1)	p > 800 bar or p < 0.0609422 bar or t > 400.0 °C or t < - 65.0 °C
Saturated liquid or vapor line:	at p = - 1000 and t > 132.36 °C or t < - 65.0°C at t = - 1000 and p > 113.6114 bar or p < 0.0609422 bar or at p > 113.6114 bar or p < 0.0609422 bar and t > 132.36 °C or t < - 65.0 °C

References: [16], [18], [21]

Specific Isobaric Heat Capacity $c_p = f(p,t,x)$

Function Name:	**cp_ptx_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION CP_PTX_NH3(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: for call from DLL	**INTEGER*4 FUNCTION C_CP_PTX_NH3(CP,P,T,X)** REAL*8 CP,P,T,X

Input values

P - Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

CP_PTX_NH3, **CP** or **cp_ptx_NH3** - Specific isobaric heat capacity c_p in kJ/(kg K)

Range of validity

Temperature range:	from – 77.65 °C to 446.85 °C
Pressure range:	from 0.0609422 bar to 10000 bar

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction *x* are to be considered:

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) x = –1 must be entered as a pro-forma value.

If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered. The calculation for x-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and p = -1000, or the given value for p and t = -1000, plus the value for x (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Saturated liquid and vapor line:	Temperature ranges from t_t = - 77.65 °C to t_c = 132.36 °C
	Pressure ranges from p_t = 0.0609422 bar to p_c = 113.6114 bar

Results for wrong input values

Result **CP_PTX_NH3, CP = - 1000 or cp_ptx_NH3 = - 1000** for input values:

Single-phase region: (x = - 1)	p > 1000 bar or p < 0.0609422 bar or t > 446.85 °C or t < - 77.650 °C
Saturated liquid or vapor line:	at p = - 1000 and t > 132.36 °C or t < - 77.65°C at t = - 1000 and p > 113.6114 bar or p < 0.0609422 bar or at p > 113.6114 bar or p < 0.0609422 bar and t > 132.36 °C or t < - 77.65 °C

References: [16], [21]

Specific Isochoric Heat Capacity $c_v = f(p,t,x)$

Function Name:	**cv_ptx_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION CV_PTX_NH3(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: for call from DLL	**INTEGER*4 FUNCTION C_CV_PTX_NH3(CV,P,T,X)** REAL*8 CV,P,T,X

Input values

P - Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

CV_PTX_NH3, **CV** or **cv_ptx_NH3** - Specific isochoric heat capacity c_v in kJ/(kg K)

Range of validity

Temperature range:	from – 77.65 °C to 446.85 °C
Pressure range:	from 0.0609422 bar to 10000 bar

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction *x* are to be considered:

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) x = –1 must be entered as a pro-forma value.

If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered. The calculation for x-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and p = -1000, or the given value for p and t = -1000, plus the value for x (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Saturated liquid and vapor line:	Temperature ranges from t_t = - 77.65 °C to t_c = 132.36 °C
	Pressure ranges from p_t = 0.0609422 bar to p_c = 113.6114 bar

Results for wrong input values:

Result **CV_PTX_NH3, CV = - 1000** or **cv_ptx_NH3 = - 1000** for input values:

Single-phase region: (x = - 1)	p > 1000 bar or p < 0.0609422 bar or t > 446.85 °C or t < - 77.650 °C
Saturated liquid or vapor line:	at p = - 1000 and t > 132.36 °C or t < - 77.65°C at t = - 1000 and p > 113.6114 bar or p < 0.0609422 bar or at p > 113.6114 bar or p < 0.0609422 bar and t > 132.36 °C or t < - 77.65 °C

References: [16], [21]

Dynamic Viscosity η = f(p,t,x)

Function Name:	**eta_ptx_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION ETA_PTX_NH3(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: for call from DLL	**INTEGER*4 FUNCTION C_ETA_PTX_NH3(ETA,P,T,X)** REAL*8 ETA,P,T,X

Input values

P - Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

ETA_PTX_NH3, **ETA** or **eta_ptx_NH3** - Dynamic viscosity η in Pa s

Range of validity

Temperature range:	from – 77.65 °C to 406.85 °C
Pressure range:	from 0.0609422 bar to 5000 bar

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction *x* are to be considered:

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) x = –1 must be entered as a pro-forma value.

If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered. The calculation for x-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and p = -1000, or the given value for p and t = -1000, plus the value for x (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Saturated liquid and vapor line:	Temperature ranges from t_t = - 77.65 °C to t_c = 132.36 °C
	Pressure ranges from p_t = 0.0609422 bar to p_c = 113.6114 bar

Results for wrong input values:

Result **ETA_PTX_NH3, ETA = - 1000** or **eta_ptx_NH3 = - 1000** for input values:

Single-phase region: (x = - 1)	p > 5000 bar or p < 0.0609422 bar or t > 406.85 °C or t < - 77.650 °C
Saturated liquid or vapor line:	at p = - 1000 and t > 132.36 °C or t < - 77.65°C at t = - 1000 and p > 113.6114 bar or p < 0.0609422 bar or at p > 113.6114 bar or p < 0.0609422 bar and t > 132.36 °C or t < - 77.65 °C

References: [17], [21]

Specific Enthalpy h = f(p,t,x)

Function Name:	**h_ptx_NH3**
Subprogram with function value: for call fromFortran	**REAL*8 FUNCTION H_PTX_NH3(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: for call from DLL	**INTEGER*4 FUNCTION C_H_PTX_NH3(H,P,T,X)** REAL*8 H,P,T,X

Input values

P - Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

H_PTX_NH3, H or **h_ptx_NH3** - Specific enthalpy h in kJ/kg

Range of validity

Temperature range: from – 77.65 °C to 446.85 °C

Pressure range: from 0.0609422 bar to 10000 bar

State of reference

Saturated liquid t = 0 °C h = h'(t = 0 °C) = 200 kJ/kg

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) x = –1 must be entered as a pro-forma value.

If the state point to be calculated is located in the wet steam region, a value for x between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. The calculation for x-values between 0 and 1 is not possible.

When calculating wet steam, it is adequate to enter either the given value for t and p = -1000, or the given value for p and t = -1000, plus the value for x (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Saturated liquid and vapor line: Temperature ranges from t_t = - 77.65 °C to t_c = 132.36 °C

Pressure ranges from p_t = 0.0609422 bar to p_c = 113.6114 bar

Results for wrong input values

Result **H_PTX_NH3, H = - 1000** or **h_ptx_NH3 = - 1000** for input values:

Single-phase region: (x = - 1)	p > 10000 bar or p < 0.0609422 bar or t > 446.85 °C or t < - 77.650 °C
Saturated liquid or vapor line:	at p = - 1000 and t > 132.36 °C or t < - 77.65°C at t = - 1000 and p > 113.6114 bar or p < 0.0609422 bar or at p > 113.6114 bar or p < 0.0609422 bar and t > 132.36 °C or t < - 77.65 °C

References: [16], [21]

Isentropic Exponent $\kappa = f(p,t,x)$

Function Name:	**kappa_ptx_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION KAP_PTX_NH3(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: for call from DLL	**INTEGER*4 FUNCTION C_KAP_PTX_NH3(KAP,P,T,X)** REAL*8 KAP,P,T,X

Input values

P - Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

KAP_PTX_NH3, **KAP** or **kappa_ptx_NH3** - Isentropic exponent $\kappa = \frac{w^2}{p * v}$

Range of validity

Temperature range:	from – 77.65 °C to 446.85 °C
Pressure range:	from 0.0609422 bar to 10000 bar

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) x = –1 must be entered as a pro-forma value.

If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered.
The calculation for x-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and p = -1000, or the given value for p and t = -1000, plus the value for x (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Saturated liquid and vapor line:	Temperature ranges from t_t = - 77.65 °C to t_c = 132.36 °C
	Pressure ranges from p_t = 0.0609 bar to p_c = 113.6114 bar

Results for wrong input values

Result **KAP_PTX_NH3, KAP = - 1000** or **kappa_ptx_NH3 = - 1000** for input values:

Single-phase region: (x = - 1)	p > 10000 bar or p < 0.0609422 bar or t > 446.85 °C or t < - 77.650 °C
Saturated liquid or vapor line:	at p = - 1000 and t > 132.36 °C or t < - 77.65°C at t = - 1000 and p > 113.6114 bar or p < 0.0609422 bar or at p > 113.6114 bar or p < 0.0609422 bar and t > 132.36 °C or t < - 77.65 °C

References: [16], [21]

Thermal Conductivity $\lambda = f(p,t,x)$

Function Name:	**lambda_ptx_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION LAM_PTX_NH3(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: for call from DLL	**INTEGER*4 FUNCTION C_LAM_PTX_NH3(LAM,P,T,X)** REAL*8 LAM,P,T,X

Input values

P - Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

LAM_PTX_NH3, **LAM** or **lambda_ptx_NH3** - Thermal conductivity λ in W / m K

Range of validity

Temperature range:	from –65.0 °C to 400.0 °C
Pressure range:	from 0.0609422 bar to 800 bar

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) x = –1 must be entered as a pro-forma value.

If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered.
The calculation for x-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and p = -1000, or the given value for p and t = -1000, plus the value for x (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Saturated liquid and vapor line:	Temperature ranges from t_t = - 77.65 °C to t_c = 132.36 °C
	Pressure ranges from p_t = 0.0609422 bar to p_c = 113.6114 bar

Results for wrong input values

Result **LAM_PTX_NH3, LAM = - 1000** or **lambda_ptx_NH3 = - 1000** for input values:

Single-phase region: (x = - 1)	p > 800 bar or p < 0.0609422 bar or t > 400.0 °C or t < - 65.0 °C
Saturated liquid or vapor line:	at p = - 1000 and t > 132.36 °C or t < - 65.0°C at t = - 1000 and p > 113.6114 bar or p < 0.0609422 bar or at p > 113.6114 bar or p < 0.0609422 bar and t > 132.36 °C or t < - 65.0 °C

References: [18], [21]

Kinematic Viscosity ν = f(p,t,x)

Function Name:	**ny_ptx_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION NY_PTX_NH3(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: for call from DLL	**INTEGER*4 FUNCTION C_NY _PTX_NH3(NY,P,T,X)** REAL*8 NY,P,T,X

Input values

P - Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

NY_PTX_NH3, **NY** or **ny_ptx_NH3** - Kinematic viscosity $\nu = \eta * v$ in m^2/s

Range of validity

Temperature range:	from – 77.65 °C to 406.85 °C
Pressure range:	from 0.0609422 bar to 5000 bar

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) x = –1 must be entered as a pro-forma value.

If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered.
The calculation for x-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and p = -1000, or the given value for p and t = -1000, plus the value for x (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Saturated liquid and vapor line: Temperature ranges from t_t = - 77.65 °C to t_c = 132.36 °C

Pressure ranges from p_t = 0.0609422 bar to p_c = 113.6114 bar

Results for wrong input values

Result **NY_PTX_NH3, NY= - 1000** or **ny_ptx_NH3 = - 1000** for input values:

Single-phase region: (x = - 1)	p > 5000 bar or p < 0.0609422 bar or t > 406.85 °C or t < - 77.650 °C
Saturated liquid or vapor line:	at p = - 1000 and t > 132.36 °C or t < - 77.65°C at t = - 1000 and p > 113.6114 bar or p < 0.0609422 bar or at p > 113.6114 bar or p < 0.0609422 bar and t > 132.36 °C or t < - 77.65 °C

References: [16], [17], [21]

Prandtl-Number Pr = f(p,t,x)

Function Name:	**Pr_ptx_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION PR_PTX_NH3(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: for call from DLL	**INTEGER*4 FUNCTION C_PR _PTX_NH3(PR,P,T,X)** REAL*8 PR,P,T,X

Input values

P - Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

PR_PTX_NH3, **PR** or **Pr_ptx_NH3** - Prandtl number $Pr = \frac{\eta * c_p}{\lambda}$

Range of validity

Temperature range:	from –65.0 °C to 400.0 °C
Pressure range:	from 0.0609422 bar to 800 bar

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) x = –1 must be entered as a pro-forma value.

If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered.
The calculation for x-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and p = -1000, or the given value for p and t = -1000, plus the value for x (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Saturated liquid and vapor line:	Temperature ranges from t_t = - 65.0 °C to t_c = 132.36 °C
	Pressure ranges from p_t = 0.0609422 bar to p_c = 113.6114 bar

Results for wrong input values

Result **PR_PTX_NH3, PR= - 1000** or **Pr_ptx_NH3 = - 1000** for input values:

Single-phase region: (x = - 1)	p > 800 bar or p < 0.0609422 bar or t > 400.0 °C or t < -65.0 °C
Saturated liquid or vapor line:	at p = - 1000 and t > 132.36 °C or t < - 65.0°C at t = - 1000 and p > 113.6114 bar or p < 0.0609422 bar or at p > 113.6114 bar or p < 0.0609422 bar and t > 132.36 °C or t < - 77.65 °C

References: [16], [17], [18], [21]

Vapor Pressure $p_s = f(t)$

Function Name:	**ps_t_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION PS_T_NH3(T)** REAL*8 T
Subprogram with parameter: for call from DLL	**INTEGER*4 FUNCTION C_PS_T_NH3(PS,T)** REAL*8 PS,T

Input value

T - Temperature t in °C

Result

PS_T_NH3, **PS** or **ps_t_NH3** - Vapor pressure p_s in bar

Range of validity

Temperature range: from – 77.65 °C to 132.36 °C

Results for wrong input values

Result **PS_T_NH3, PS = - 1000** or **ps_t_NH3 = - 1000** for input values:

t < - 77.65 °C or t > 132.36 °C

References: [16], [21]

Density $\rho = f(p,t,x)$

Function Name:	**rho_ptx_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION RHO_PTX_NH3(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: for call from DLL	**INTEGER*4 FUNCTION C_RHO_PTX_NH3(RHO,P,T,X)** REAL*8 RHO,P,T,X

Input values

P – Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

RHO_PTX_NH3, **RHO** or **rho_ptx_NH3** - Density ρ in kg/m^3

Range of validity

Temperature range:	from – 77.65 °C to 446.85 °C
Pressure range:	from 0.0609422 bar to 10000 bar

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) x = –1 must be entered as a pro-forma value.

If the state point to be calculated is located in the wet steam region, a value for x between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. The calculation for x-values between 0 and 1 is not possible.

When calculating wet steam, it is adequate to enter either the given value for t and p = -1000, or the given value for p and t = -1000, plus the value for x (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Saturated liquid and vapor line: Temperature ranges from t_t = - 77.65 °C to t_c = 132.36 °C

Pressure ranges from p_t = 0.0609422 bar to p_c = 113.6114 bar

Results for wrong input values

Result **RHO_PTX_NH3, RHO= - 1000** or **rho_ptx_NH3 = - 1000** for input values:

Single-phase region: (x = - 1)	p > 10000 bar or p < 0.0609422 bar or t > 446.85 °C or t < - 77.650 °C
Saturated liquid or vapor line:	at p = - 1000 and t > 132.36 °C or t < - 77.65°C at t = - 1000 and p > 113.6114 bar or p < 0.0609422 bar or at p > 113.6114 bar or p < 0.0609422 bar and t > 132.36 °C or t < - 77.65 °C

References: [16], [21]

Specific Entropy s = f(p,t,x)

Function Name:	**s_ptx_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION S_PTX_NH3(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: for call from DLL	**INTEGER*4 FUNCTION C_S_PTX_NH3(S,P,T,X)** REAL*8 S,P,T,X

Input values

P - Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

S_PTX_NH3, S or **s_ptx_NH3** - Specific entropy s in kJ/kg K

Range of validity

Temperature range: from – 77.65 °C to 446.85 °C

Pressure range: from 0.0609422 bar to 10000 bar

State of reference

Saturated liquid t = 0 °C s = s'(t = 0 °C) = 1 kJ/(kg K)

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) x = –1 must be entered as a pro-forma value.

If the state point to be calculated is located in the wet steam region, a value for x between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. The calculation for x-values between 0 and 1 is not possible.

When calculating wet steam, it is adequate to enter either the given value for t and p = -1000, or the given value for p and t = -1000, plus the value for x (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Saturated liquid and vapor line: Temperature ranges from t_t = - 77.65 °C to t_c = 132.36 °C

Pressure ranges from p_t = 0.0609422 bar to p_c = 113.6114 bar

Results for wrong input values

Result **S_PTX_NH3, S = - 1000** or **s_ptx_NH3 = - 1000** for input values:

Single-phase region: (x = - 1)	p > 10000 bar or p < 0.0609422 bar or t > 446.85 °C or t < - 77.650 °C
Saturated liquid or vapor line:	at p = - 1000 and t > 132.36 °C or t < - 77.65°C at t = - 1000 and p > 113.6114 bar or p < 0.0609422 bar or at p > 113.6114 bar or p < 0.0609422 bar and t > 132.36 °C or t < - 77.65 °C

References: [16], [21]

Backward Function: Temperature t = f(p,h)

Function Name:	**t_ph_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION T_PH_NH3(P,H)** REAL*8 P,H
Subprogram with parameter: for call from DLL	**INTEGER*4 FUNCTION C_T _PH_NH3(T,P,H)** REAL*8 T,P,H

Input values

P - Pressure p in bar

H - Specific enthalpy h in kJ/kg

Result

T_PH_NH3, T or **t_ph_NH3** – Temperature t in °C

Range of validity

Temperature range:	from – 77.65 °C to 446.85 °C
Pressure range:	from 0.0609422 bar to 10000 bar

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of p and h the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of t in the appropriate region will be carried out.

Wet steam region: Pressure ranges from p_t = 0.0609422 bar to p_c = 113.6114 bar

Results for wrong input values

Result **T_PH_NH3, T = - 1000** or **t_ph_NH3 = - 1000** for input values:

Single-phase region: (x = - 1)	p > 10000 bar or p < 0.0609422 bar or in case of the result of calculation t > 446.85 °C or t < - 77.650 °C
Saturated liquid or vapor line:	at p > 113.6114 bar or p < 0.0609 bar or in case of the result of calculation t > 132.36 °C or t < - 77.65 °C

References: [16], [21]

Backward Function: Temperature t = f(p,s)

Function Name:	**t_ps_NH3**
Subprogramwith function value: for call from Fortran	**REAL*8 FUNCTION T_PS_NH3(P,S)** REAL*8 P,S
Subprogramwith parameter: for call from DLL	**INTEGER*4 FUNCTION C_T_PS_NH3(T,P,S)** REAL*8 T,P,S

Input values

P - Pressure p in bar

S - Specific entropy s in kJ/kg K

Result

T_PS_NH3, T or **t_ps_NH3** – Temperature t in °C

Range of validity

Temperature range:	from – 77.65 °C to 446.85 °C
Pressure range:	from 0.0609422 bar to 10000 bar

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of p and s the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of t in the appropriate region will be carried out.

Wet steam region: Pressure ranges from p_t = 0.0609422 bar to p_c = 113.6114 bar

Results for wrong input values

Result **T_PS_NH3, T = -1000** or **t_ps_NH3 = -1000** for input values:

Single-phase region: p > 10000 bar or p < 0.0609422 bar or
(x = - 1) in case of the result of calculation t > 446.85 °C or t < - 77.650 °C

Saturated liquid or vapor line: at p > 113.6114 bar or p < 0.0609 bar or
in case of the result of calculation t > 132.36 °C or t < - 77.65 °C

References: [16], [21]

Saturation Temperature $t_s = f(p)$

Function Name:	**ts_p_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION TS_P_NH3(P)** REAL*8 P
Subprogram with parameter: for call from DLL	**INTEGER*4 FUNCTION C_TS_P_NH3(TS,P)** REAL*8 TS,P

Input value

P - Pressure p in bar

Result

TS_P_NH3, **TS** or **ts_p_NH3** - Saturation temperature t_s in °C

Range of validity

Pressure range: from 0.0609422 bar to 113.6114 bar

Results for wrong input values

Result **TS_P_NH3, TS = - 1000** or **ts_p_NH3 = - 1000** for input values:

p < 0.0609422 bar or p > 113.6114 bar

References: [16], [21]

Specific Internal Energy u = f(p,t,x)

Function Name:	**u_ptx_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION U_PTX_NH3(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: for call from DLL	**INTEGER*4 FUNCTION C_U_PTX_NH3(U,P,T,X)** REAL*8 U,P,T,X

Input values

P - Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

U_PTX_NH3, U or **u_ptx_NH3** – Specific internal energy u in kJ/kg

Range of validity

Temperature range:	from – 77.65 °C to 446.85 °C
Pressure range:	from 0.0609422 bar to 10000 bar

State of reference

Saturated liquid t = 0 °C with h = h'(t = 0 °C) = 200 kJ/kg follows u=199,328 kJ/kg

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) x = –1 must be entered as a pro-forma value.

If the state point to be calculated is located in the wet steam region, a value for x between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. The calculation for x-values between 0 and 1 is not possible.

When calculating wet steam, it is adequate to enter either the given value for t and p = -1000, or the given value for p and t = -1000, plus the value for x (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Saturated liquid and vapor line: Temperature ranges from t_t = - 77.65 °C to t_c = 132.36 °C

Pressure ranges from p_t = 0.0609422 bar to p_c = 113.6114 bar

Results for wrong input values

Result **U_PTX_NH3, U = - 1000** or **u_ptx_NH3 = - 1000** for input values:

Single-phase region: (x = - 1)	p > 10000 bar or p < 0.0609422 bar or t > 446.85 °C or t < - 77.650 °C
Saturated liquid or vapor line:	at p = - 1000 and t > 132.36 °C or t < - 77.65°C at t = - 1000 and p > 113.6114 bar or p < 0.0609422 bar or at p > 113.6114 bar or p < 0.0609422 bar and t > 132.36 °C or t < - 77.65 °C

References: [16], [21]

Specific Volume v = f(p,t,x)

Function Name:	**v_ptx_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION V_PTX_NH3(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: for call from DLL	**INTEGER*4 FUNCTION C_V_PTX_NH3(V,P,T,X)** REAL*8 V,P,T,X

Input values

P - Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

V_PTX_NH3, **V** or **v_ptx_NH3** - Specific volume v in m^3/kg

Range of validity

Temperature range: from – 77.65 °C to 446.85 °C

Pressure range: from 0.0609422 bar to 10000 bar

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) x = –1 must be entered as a pro-forma value.

If the state point to be calculated is located in the wet steam region, a value for x between 0 and 1 (x = 0 for saturated liquid, x = 1 for saturated steam) must be entered. The calculation for x-values between 0 and 1 is not possible.

When calculating wet steam, it is adequate to enter either the given value for t and p = -1000, or the given value for p and t = -1000, plus the value for x (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Saturated liquid and vapor line: Temperature ranges from t_t = - 77.65 °C to t_c = 132.36 °C

Pressure ranges from p_t = 0.0609422 bar to p_c = 113.6114 bar

Results for wrong input values

Result **V_PTX_NH3, V = - 1000** or **v_ptx_NH3 = - 1000** for input values:

Single-phase region: (x = - 1)	p > 10000 bar or p < 0.0609422 bar or t > 446.85 °C or t < - 77.650 °C
Saturated liquid or vapor line:	at p = - 1000 and t > 132.36 °C or t < - 77.65°C at t = - 1000 and p > 113.6114 bar or p < 0.0609422 bar or at p > 113.6114 bar or p < 0.0609422 bar and t > 132.36 °C or t < - 77.65 °C

References: [16], [21]

Isentropic Speed of Sound w = f(p,t,x)

Function Name:	**w_ptx_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION W_PTX_NH3(P,T,X)** REAL*8 P,T,X
Subprogram with parameter: for call fromDLL	**INTEGER*4 FUNCTION C_W_PTX_NH3(W,P,T,X)** REAL*8 W,P,T,X

Input values

P - Pressure p in bar

T - Temperature t in °C

X – Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

W_PTX_NH3, W or **w_ptx_NH3** – Speed of sound w in m/s

Range of validity

Temperature range:	from – 77.65 °C to 446.85 °C
Pressure range:	from 0.0609422 bar to 10000 bar

Details on the vapor fraction *x* and on the calculation of saturated liquid and saturated steam

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) x = –1 must be entered as a pro-forma value.

If the state point to be calculated is located on the saturated liquid line, x = 0 must be entered. When calculating saturated steam (saturated vapor line) x = 1 must be entered.
The calculation for x-values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and p = -1000, or the given value for p and t = -1000, plus the value for x (x = 0 or x = 1). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

Saturated liquid and vapor line: Temperature ranges from t_t = - 77.65 °C to t_c = 132.36 °C

Pressure ranges from p_t = 0.0609422 bar to p_c = 113.6114 bar

Results for wrong input values

Result **W_PTX_NH3, W = - 1000** or **w_ptx_NH3 = - 1000** for input values:

Single-phase region: (x = - 1)	p > 10000 bar or p < 0.0609422 bar or t > 446.85 °C or t < - 77.650 °C
Saturated liquid or vapor line:	at p = - 1000 and t > 132.36 °C or t < - 77.65°C at t = - 1000 and p > 113.6114 bar or p < 0.0609422 bar or at p > 113.6114 bar or p < 0.0609422 bar and t > 132.36 °C or t < - 77.65 °C

References: [16], [21]

Backward Function: Vapor Fraction x = f(p,h)

Function Name:	**x_ph_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION X_PH_NH3(P,H)** REAL*8 P,H
Subprogram with parameter: for call from DLL	**INTEGER*4 FUNCTION C_X_PH_NH3(T,P,H)** REAL*8 X,P,H

Input values

P - Pressure p in bar

H - Specific enthalpy h in kJ/kg

Result

X_PH_NH3, X or **x_ph_NH3** – Vapor fraction x in (kg saturated steam/kg wet steam)

Range of validity

Temperature range:	from – 77.65 °C to 446.85 °C
Pressure range:	from 0.0609422 bar to 10000 bar

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of p and h the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. When calculating wet steam the value for x between 0 and 1 is calculated (0 for saturated liquid, 1 for saturated steam). If the state point to be calculated is located in the single-phase region the result x = - 1 will be returned.

Wet steam region: Pressure ranges from $p_t = 0.0609422$ bar to $p_c = 113.6114$ bar

Results for wrong input values

Result **X_PH_NH3, X = - 1** or **x_ph_NH3 = - 1** for input values:

In case the point of state to be calculated is situated in the single-phase region
p > 113.6114 bar or p < 0.0609422 bar

References: [16], [21]

Backward Function: Vapor Fraction x = f(p,s)

Function Name:	**x_ps_NH3**
Subprogram with function value: for call from Fortran	**REAL*8 FUNCTION X_PS_NH3(P,S)** REAL*8 P,S
Subprogram with parameter: for call from DLL	**INTEGER*4 FUNCTION C_X_PS_NH3(X,P,S)** REAL*8 X,P,S

Input values

P - Pressure p in bar

S - Specific entropy s in kJ/kg K

Result

X_PS_NH3, T or **x_ps_NH3** – Vapor fraction x in (kg saturated steam/kg wet steam)

Range of validity

Temperature range:	from – 77.65 °C to 446.85 °C
Pressure range:	from 0.0609422 bar to 10000 bar

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of p and s the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. When calculating wet steam the value for x between 0 and 1 is calculated (0 for saturated liquid, 1 for saturated steam). If the state point to be calculated is located in the single-phase region the result x = - 1 will be returned.

Wet steam region: Pressure ranges from $p_t = 0.0609422$ bar to $p_c = 113.6114$ bar

Results for wrong input values

Result **X_PS_NH3, X = - 1** or **x_ps_NH3 = - 1** for input values:

In case the point of state to be calculated is situated in the single-phase region
p > 113.6114 bar or p < 0.0609422 bar

References: [16], [21]

KCE

KCE-ThermoFluidProperties
www.thermofluidprop.com

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)

Library LibSBTL_IF97
Library LibSBTL_95

Extremely fast property calculations according to the IAPWS Guideline 2015
Spline-based Table Look-up Method (SBTL)
applied to the
Industrial Formulation IAPWS-IF97
and to the
Scientific Formulation IAPWS-95
for Computational Fluid Dynamics and simulating non-stationary processes

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:

CO_2 - Span, Wagner H_2O - IAPWS-95
O_2 - Schmidt, Wagner N_2 - Span et al.
Ar - Tegeler et al.

and of the ideal gases:

SO_2, CO, Ne
(Scientific Formulation of Bücker et al.)

Consideration of:

- Dissociation from VDI 4670
- Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:

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

Consideration of:

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

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

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

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

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

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Humid Air

Library ASHRAE LibHuAirProp

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

Consideration of:

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

www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bücker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bücker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

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

Helmholtz energy equation for the mixing term

(also useable for calculating the Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

$C_2H_6O_2$	Ethylene glycol
$C_3H_8O_2$	Propylene glycol
C_2H_5OH	Ethanol
CH_3OH	Methanol
$C_3H_8O_3$	Glycerol
K_2CO_3	Potassium carbonate
$CaCl_2$	Calcium chloride
$MgCl_2$	Magnesium chloride
NaCl	Sodium chloride
$C_2H_3KO_2$	Potassium acetate
$CHKO_2$	Potassium formate
LiCl	Lithium chloride
NH_3	Ammonia

Formulation of the International Institute of Refrigeration (IIR 2010)

Ethanol
Library LibC2H5OH
Formulation of
Schroeder (2012)

Methanol
Library LibCH3OH
Formulation of
de Reuck and Craven (1993)

Propane
Library LibPropane
Formulation of
Lemmon et al. (2009)

Siloxanes as ORC Working Fluids

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

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

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

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

Formulation of Colonna et al. (2006)

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

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

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

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

Formulation of Colonna et al. (2008)

Nitrogen and Oxygen
Libraries
LibN2 and LibO2
Formulations of Span et al. (2000)
and Schmidt and Wagner (1985)

Hydrogen
Library LibH2
Formulation of
Leachman et al. (2009)

Helium
Library LibHe
Formulation of
Arp et al. (1998)

Hydrocarbons

Decane $C_{10}H_{22}$ **Library LibC10H22**
Isopentane C_5H_{12} **Library LibC5H12_ISO**
Neopentane C_5H_{12} **Library LibC5H12_NEO**
Isohexane C_6H_{14} **Library LibC6H14**
Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

Carbon monoxide **CO** **Library LibCO**
Carbonyl sulfide **COS** **Library LibCOS**
Hydrogen sulfide H_2S **Library LibH2S**
Nitrous oxide N_2O **Library LibN2O**
Sulfur dioxide SO_2 **Library LibSO2**
Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

For more information please contact:

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Mobile: +49-172-7914607
Fax: +49-3222-4262250

The following thermodynamic and transport properties can be calculated[a]:

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

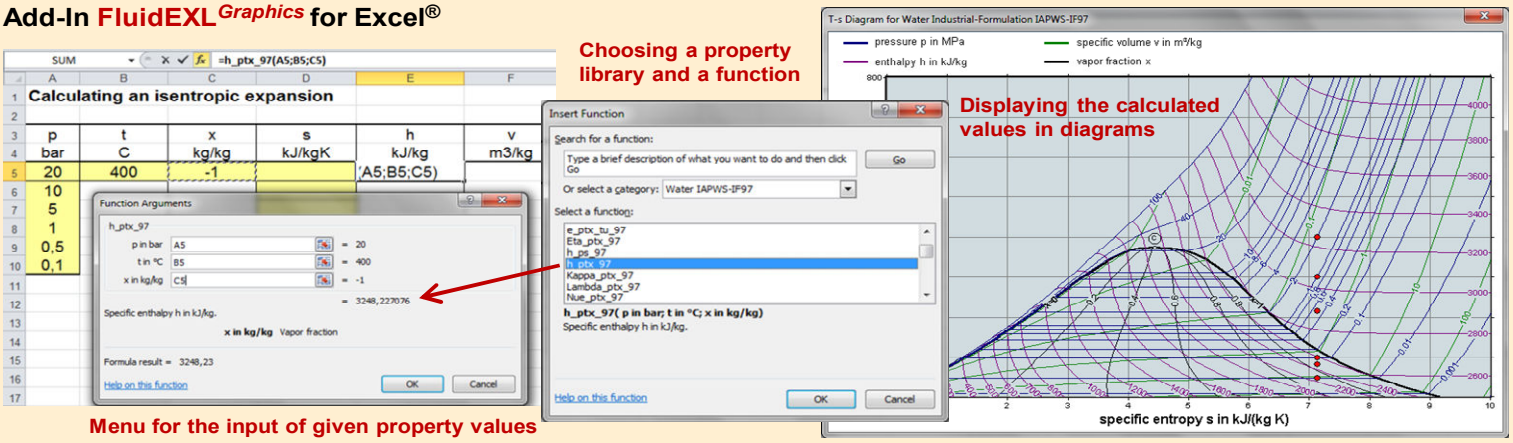
- Partial derivatives can be calculated.

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

KCE-ThermoFluidProperties
www.thermofluidprop.com

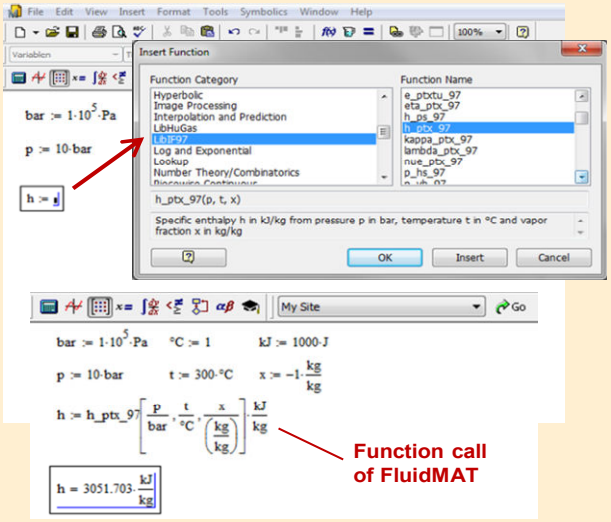
Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Add-In FluidEXL*Graphics* for Excel®



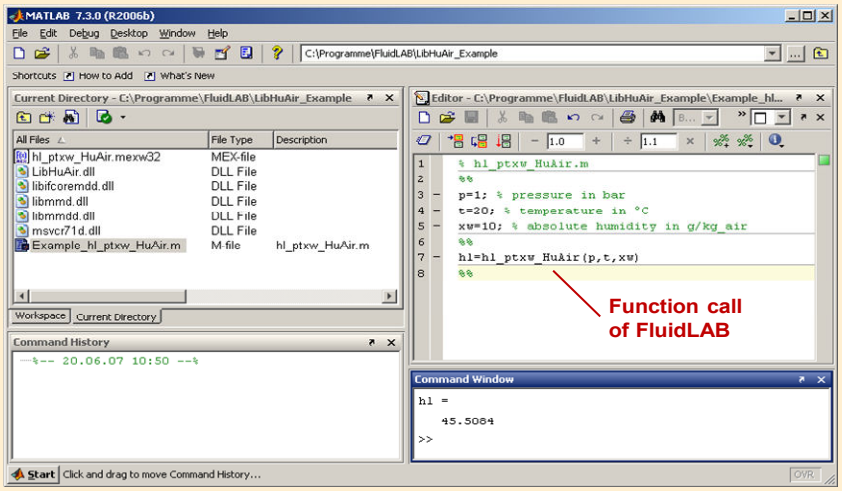
Add-In FluidMAT for Mathcad®

The property libraries can be used in Mathcad®.



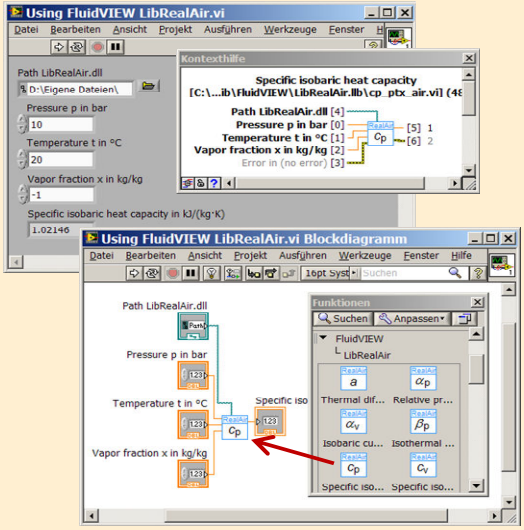
Add-In FluidLAB for MATLAB®

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



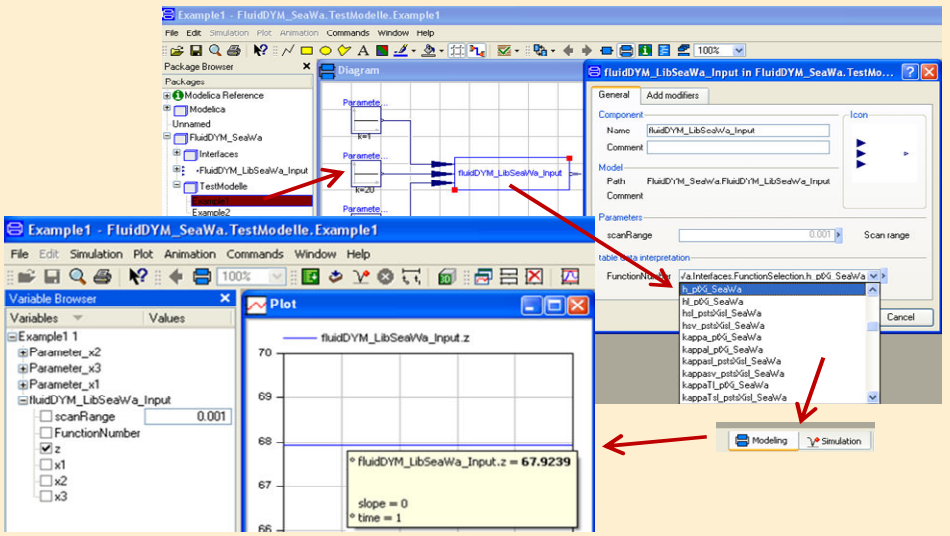
Add-On FluidVIEW for LabVIEW™

The property functions can be calculated in LabVIEW™.

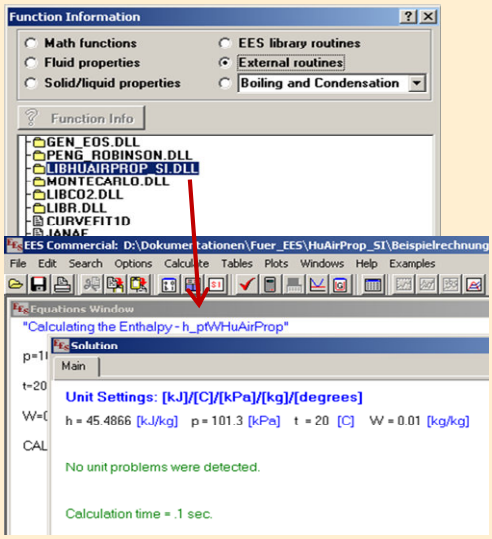


Add-In FluidDYM for DYMOLA® (Modelica) and SimulationX®

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

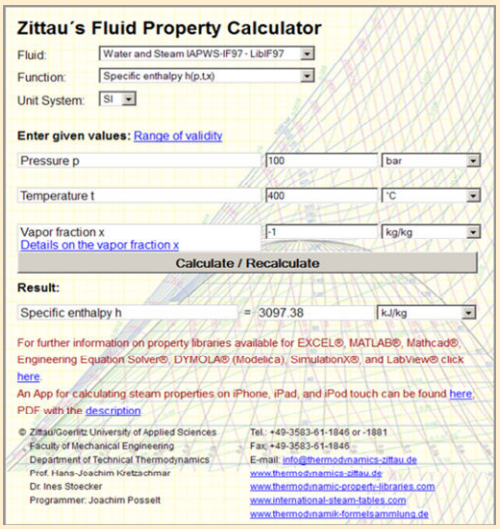


Add-In FluidEES for Engineering Equation Solver®



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

Online Property Calculator at www.thermofluidprop.com



Property Software for Pocket Calculators

FluidCasio

fx 9750 G II | CFX 9850 fx-GG20 | CFX 9860 G Graph 85 | ALGEBRA FX 2.0

FluidHP

HP 48 | HP 49

FluidTI

TI Nspire CX CAS
TI Nspire CAS
TI 83
TI 84
TI 89
TI Voyage 200
TI 92

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

Thermodynamic Properties

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

Transport Properties

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

Backward Functions

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

Thermodynamic Derivatives

- Partial derivatives can be calculated.

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

www.thermofluidprop.com

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6. Satisfied Customers

Date: 07/2019

The following companies and institutions use the property libraries:

- FluidEXL*Graphics* for Excel®
- FluidLAB for MATLAB® and Simulink
- FluidMAT for Mathcad®
- FluidPRIME for Mathcad Prime®
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2019

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Witt Consulting Engineers, Stade	03/2011
Helbling, Zurich, Switzerland	03/2011
MAN Diesel, Copenhagen, Denmark	03/2011
AGO, Kulmbach	03/2011
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Calorifer, Elgg, Switzerland	01/2011
STRABAG, Vienna, Austria	01/2011
TUEV Sued, Munich	01/2011

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Technical University of Dresden	01/2011, 05/2011
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2010

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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
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Glen Dimplex, Kulmbach	05/2010, 07/2010
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2009

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EPP Software, Marburg	03/2009
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CPP, Marburg	03/2009
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Gatley & Associates, Atlanta, USA	05/2009
BOSCH, Stuttgart	06/2009, 07/2009
Dr. Nickolay, Consulting Engineers, Gommersheim	06/2009
Ferrostal Power, Saarlouis	06/2009
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Wienstrom, Vienna, Austria	08/2009
RWTH Aachen University	09/2009
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Institute of Air Handling and Refrigeration ILK, Dresden	11/2009
FZD, Rossendorf	11/2009
Techgroup, Ratingen	11/2009
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EC, Heidelberg	11/2009
MCI, Innsbruck, Austria	12/2009
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ENERKO, Aldenhoven	12/2009

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ARUP, Berlin	05/2008
Research Center, Karlsruhe	07/2008
AWECO, Neukirch	07/2008
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Technical University of Cottbus, Chair in Power Plant Engineering	07/2008, 10/2008
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Technip Benelux BV, Zoetermeer, Netherlands	08/2008
Fennovoima Oy, Helsinki, Finland	08/2008
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PEU, Espenhain	09/2008
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WINGAS, Kassel	09/2008
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AWTEC, Zurich, Switzerland	11/2008
Siemens Power Generation, Erlangen	12/2008

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University of Stuttgart, Chair in Aviation Propulsions	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
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Voith Paper Air Systems, Bayreuth	06/2007
Egger Holzwerkstoffe, Wismar	06/2007
Tissue Europe Technologie, Mannheim	06/2007
Dometic, Siegen	07/2007
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Wiesbaden University of Applied Sciences, Department of Engineering Sciences	10/2007
Endress+Hauser Messtechnik, Hannover	11/2007
Munich University of Applied Sciences, Department of Mechanical Engineering	11/2007
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University of Rostock, Chair in Technical Thermodynamics	11/2007, 12/2007

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KOCH Transporttechnik, Wadgassen	01/2006
BEG Bremerhavener Entsorgungsgesellschaft	02/2006
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University of Stuttgart,	02/2006

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RWE Power, Essen	03/2006
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EnviCon & Plant Engineering, Nuremberg	04/2006
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Department of USET Merseburg incorporated society	
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Enertech Energie und Technik, Radebeul	12/2006

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J.H.K Plant Engineering and Service, Bremerhaven	01/2005
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FCIT, Stuttgart	01/2005
Energietechnik Leipzig (company license)	02/2005, 04/2005
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eta Energieberatung, Pfaffenhofen	02/2005
FZR Forschungszentrum, Rossendorf/Dresden	04/2005
University of Saarbruecken	04/2005
Technical University of Dresden	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, 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
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Basel University of Applied Sciences, Department of Mechanical Engineering, Switzerland	10/2005
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h s energieanlagen, Freising	07/2004
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MAN Turbo Machines, Oberhausen	09/2004
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energeticals (e-concept), Munich	11/2004
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Wulff Energy Systems, Husum	01/2003
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Rietschle Energieplaner, Winterthur, Switzerland	02/2003
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ENERKO, Aldenhoven	08/2003
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exergie, Dresden	09/2003
AWTEC, Zurich, Switzerland	09/2003
Energie, Timelkam, Austria	09/2003
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LG, Annaberg-Buchholz	10/2003
FZR Forschungszentrum, Rossendorf/Dresden	10/2003
EnviCon & Plant Engineering, Nuremberg	11/2003
Visteon, Kerpen	11/2003
VEO Vulkan Energiewirtschaft Oderbruecke, Eisenhuettenstadt	11/2003
Stadtwerke Hannover	11/2003
SaarEnergie, Saarbruecken	11/2003
Fraunhofer-Gesellschaft, Munich	12/2003
Erfurt University of Applied Sciences, Department of Supply Engineering	12/2003
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DVO Data Processing Service, Oberhausen	05/2000
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Technical University of Graz, Department of Thermal Engineering, Austria	11/1999
Ostendorf Engineering, Gummersbach	12/1999

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Alfa Engineering, Switzerland	09/1998
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SCA Hygiene Products, Munich	10/1998
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