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Software for the IAPWS-IF97 Industrial Formulation for Water und Steam

FluidTI
for the
TI 89, TI 92, TI voyage 200 Pocket Calculators

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Software for the Industrial-Formulation IAPWS-IF97 for Water and Steam

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Contents

For further pocket calculator software see the following link:

www.steamtables-pocket-calculators.com

For steam tables and further property libraries for Excel® and Mathcad® see the following link:

www.international-steam-tables.com

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1. Property Functions for Water and Steam

The FluidTI program for the TI 89, TI 92, TI 92Plus, and TI voyage 200 Pocket Calculators contains the following functions for the calculation of thermodynamic properties of water and steam:

Functional Dependence	**Name in FluidTI**	**Property or Function**	**Unit**
$p_s = f(t)$	ps_t_97	Saturation pressure	MPa
$t_s = f(p)$	ts_p_97	Saturation temperature	°C
$v = f(p,t,x)$	v_ptx_97	Specific volume	m^3/kg
$h = f(p,t,x)$	h_ptx_97	Specific enthalpy	kJ/kg
$s = f(p,t,x)$	s_ptx_97	Specific entropy	kJ/(kg · K)
$t = f(p,h)$	t_ph_97	Backward function: temperature from pressure and enthalpy	°C
$x = f(p,h)$	x_ph_97	Backward function: vapor fraction from pressure and enthalpy	kg/kg
$t = f(p,s)$	t_ps_97	Backward function: temperature from pressure and entropy	°C
$x = f(p,s)$	x_ps_97	Backward function: vapor fraction from pressure and entropy	kg/kg
$\eta = f(p,t,x)$	eta_ptx_97	Dynamic viscosity	Pa · s = kg/(m · s)
$\lambda = f(p,t,x)$	lambda_ptx_97	Thermal conductivity	W/(m · K)
$c_p = f(p,t,x)$	cp_ptx_97	Specific isobaric heat capacity	kJ/(kg · K)

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

Range of Validity: IAPWS-IF97 regions 1 and 2, including wet steam
Pressure: from 0.000611 MPa up to 100 MPa
Temperature: from 0 °C up to 800 °C

Comment on the vapor fraction *x* and calculations for wet steam

The subprograms automatically deal with the wet steam region. For this purpose the following specifications for the vapor fraction *x* are to be regarded:

If the state point to be calculated is located within the single-phase regions (of liquid or superheated steam) enter either no input value, or -1 for the value of *x.* In this case, the backward functions will result in x = -1.

If the state point to be calculated is located within the two-phase region (wet steam), values between 0 and 1 have to be entered for the value of *x* (x = 0 for saturated liquid, x = 1 for saturated vapor). The backward functions result in values for *x* that range from 0 to 1.

In the case of wet steam it is adequate to put in either the value given for t and p = -1 (or no input value for p), or the given value for p and t = -1 (or no input value for t), as well as the value for *x* that ranges from 0 to1.

If you enter *p* and *t* and *x* when calculating wet steam, the program considers *p* and *t* to meet the vapor-pressure curve. If this does not apply, an error message is displayed for the selected function to be calculated.

IAPWS-F97 wet steam region: t = 0 °C ... t = 373.946 °C
p = 0.000611 MPa ... p = 22.064 MPa

Please note.

If the calculation results in -1, values have been entered outside the range of validity of the IAPWS-IF97 or they do not define a state point. In this case, an error message is displayed.

2. Range of Validity and the FluidTI Program Structure

The International Association for the Properties of Water and Steam (IAPWS) issued the IAPWS-IF97 Industrial Formulation for Thermodynamic Properties of Water and Steam in 1997. This standard must be applied worldwide in final warranty calculations for power plants which use water and steam as working fluid.

Figure 1 shows the range of validity of the equation set of the Industrial Formulation, fully named

"IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam",

abbreviated

"IAPWS-IF97".

The IAPWS-IF97 range of state includes temperatures from 0 °C up to 800 °C at pressures from 0.000611 up to 100 MPa and temperatures up to 2000 °C at pressures up to 50 MPa.

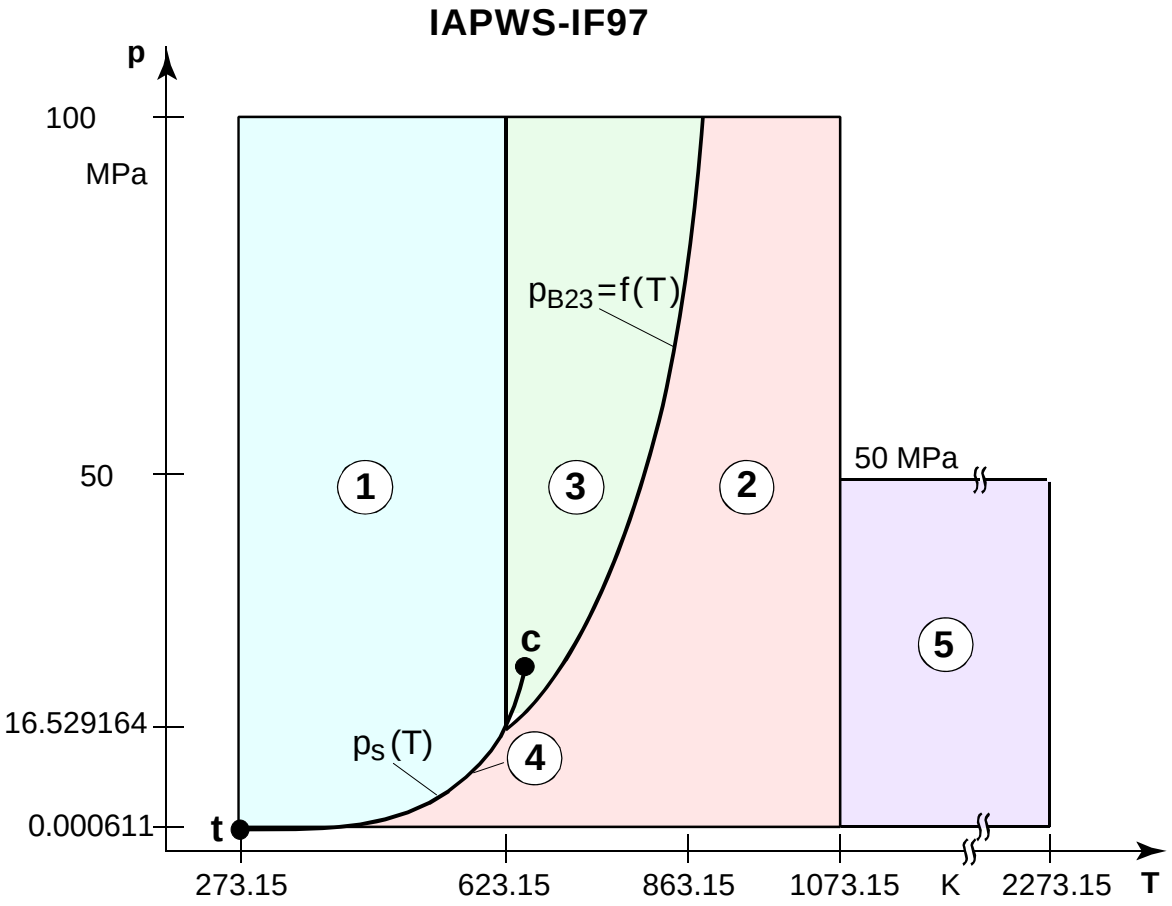


Figure 1: Entire IAPWS-IF97 range of validity

Internally, the entire range of validity is subdivided into five calculation regions in which the appropriate constitutive equations apply (cf. Fig. 1). Those are described in detail in the official IAPWS [1] release and in the publications by *Wagner et al.* [2] and [3].

The FluidTI version at hand is valid for the regions 1, 2, and the wet steam region (region 4) up to a pressure of 16.529164 MPa (cf. Figure1). Their connection to the calculation equations is established according to the given quantities.

3. Application of FluidTI

3.1 Installation of FluidTI onto the TI 89, TI 92, TI 92Plus, and TI voyage 200 Pocket Calculators

In order to run the FluidTI software on your pocket calculator, load the program from your computer into the calculator, using a special link program and the appropriate link cable.

The link program is available at service partners of Texas Instruments®, as well as the link cable, or can be downloaded from the TI web site: http://www.ti.com/calc/docs/link.htm.

The following description is valid for the

TI-Graph-Link® and TI-Connect®

link programs which should have already been installed onto your computer.

(For another link program used for the file transfer see the corresponding user's guide or online-help.)

1. Insert the FluidTI CD into your CD-ROM drive. The CD contains the group files listed in the following table:

TI Model	**TI 89**	**TI 92**	**TI 92 E[1]**	**TI 92Plus**	**TI voyage 200**
Group File	IF97_89.89g	IF97_92.92g	IF97_92E.92g	IF97_92P.9xg	IF97_voyage_200.9xg

[1] Model TI 92 including memory extension

2. Connect the TI calculator to the PC using the serial link cable or the USB cable.

   If the TI-Connect® link program is used for data transfer please follow paragraph 4.

3. Data Transfer with the TI-Graph-Link®

- Start the TI-Graph-Link® program on your computer.
- Open the "Link" menu and click "Send...".
- Choose your CD drive in the "Drives" window.

In the window "File Name:" the group file name(s) relating to the model connected is (are) displayed.

Please note that there are two group files available for the TI 92 (cf. above Table).

The file "IF97_voyage_200.9xg" for the TI voyage 200 is displayed as IF97_v~1.9xg.

- Click the name that belongs to the TI model at hand and click the "Add" button.

In the lower "Files Selected:" window, the group file name and the appropriate CD drive are shown.

- Select "Retain Folder".

Make sure the TI calculator is switched on.

- Click "OK" to send the files to the TI calculator. A window on your computer displays the list of the files received by the TI.
- As soon as the file transfer is complete click "OK" in order to return to the desktop.

The installation of FluidTI on your pocket calculator is complete.

If the files have not been copied to the pocket calculator the transfer failed due to one of the following errors:

- The TI has not been switched on or was not connected to the computer when the TI-Graph-Link® program was started.
- An inappropriate communication port has been selected (COM 1 ... COM 2 in the "Link" menu).
- The TI cursor has not been located in the command line when the file transfer was started.
- An inappropriate link cable has been used or selected in the "Cable type" menu.
- The link cable has not been plugged in properly.

4. Data Transfer with the TI-Connect®

Make sure the TI calculator is switched on.

- Start the TI-Connect® program on your computer.
- Click the "TI DeviceExplorer".

It is possible that the "TI Communication Settings" menu pops up.

The name of the TI calculator, the cable name, and the port used for the cable are listed.

- Check the names in the list and confirm them by clicking the "OK" button.

The TI-Connect® now tries to gain access to the TI calculator. After the link program has gained access, the directory tree of the connected TI calculator is displayed.

- Click "Tools" in the upper menu bar and "TI GroupExplorer".
- Search your CD drive and click "+" on the right-hand side.

The group files are displayed below.

- Click the file that belongs to the TI model at hand (cf. above Table).
- Right-click this file. The context menu is displayed.
- Click "Send To Device".

Now, the data transfer from the computer to the TI calculator starts. The files copied are displayed in a window on the computer.

The directory "FLUIDTI" has been set up in the TI calculator; the program files have been copied into this directory.

If the files have not been copied to the pocket calculator the transfer failed due to one of the following errors:

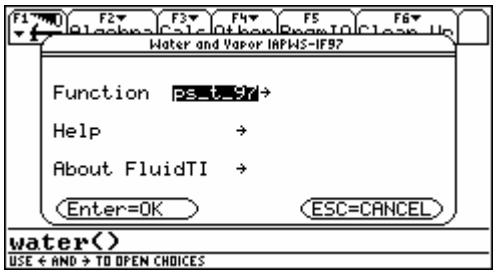
- The TI has not been switched on or connected to the computer when the TI-Connect® was started.
- The TI cursor has not been located in the command line when the file transfer was started.
- An inappropriate link cable has been used.
- The link cable has not been plugged in properly.

3.2 Example: Calculation of *h* = f(*p*,*t*,*x*) using FluidTI

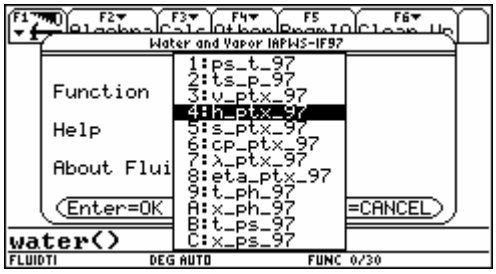
The specific enthalpy *h* as a function of pressure *p*, temperature *t* and vapor fraction *x* can be calculated for the Industrial Formulation IAPWS-IF97 on the TI 89, TI 92, TI 92Plus, or the TI voyage 200.

Please carry out the following steps:

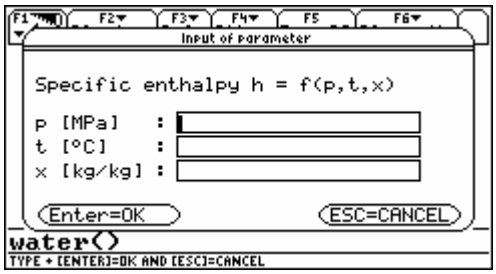
- Press <MODE> and move the cursor to "Current Folder...".
  Move the cursor right, choose "fluidti" and press the <ENTER> key.
  Now, "fluidti" flashes in the "Current Folder" field.
  Press <ENTER> again. "FLUIDTI" arises in the lower left-hand corner of the screen.
- Now, enter "water()" in the command line and press the <ENTER> key.
- The starting menu of FluidTI is displayed. Press <ENTER>.
  The main menu of FluidTI is displayed:



  The property function "ps_t_97" flashes.
- Move the cursor right to the open "Function" menu.
  All functions which can be calculated are listed:



- Move the cursor to the function "4: h_ptx_97" and press <ENTER>.
  In the main menu, the function "h_ptx_97" flashes now. Press <ENTER>.
- The following menu "Input of parameters" is displayed:



- Enter the given value for "p in MPa" into the appropriate window. Please consider the IAPWS-IF97 range of validity:

  p = 0.000611 MPa ... 100 MPa.

  → E.g.: Enter the value 10 and move the cursor to the next input field.

- Enter the value given for "t in °C" into the appropriate window. Please consider the IAPWS-IF97 range of validity:

  t = 0 °C ... 800 °C.

  → E.g.: Enter the value 400, and move the cursor to the next input field.

- Now, the value for the vapor fraction *x* in (kg saturated steam/kg wet steam) is to be entered into the appropriate window. Consider the following specifications:

  If the state point to be calculated is located within the single-phase regions (of liquid or superheated steam) enter either no input value, or -1 for the value of *x*. In this case, the backward functions will result in x = -1.

  If the state point to be calculated is located within the two-phase region (wet steam), values between 0 and 1 have to be entered for the value of *x* (x = 0 for saturated liquid, x = 1 for saturated vapor). The backward functions result in values for *x* that range from 0 to 1.

  In the case of wet steam it is adequate to put in either the value given for t and p = -1 (or no input value for p), or the given value for p and t = -1 (or no input value for t), as well as the value for *x* that ranges from 0 to1.

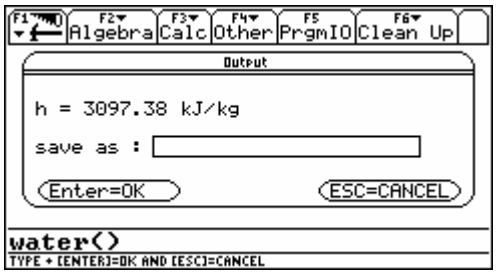
  If you enter *p* and *t* and *x* when calculating wet steam, the program considers *p* and *t* to meet the vapor-pressure curve. If this does not apply, an error message is displayed for the selected function to be calculated.

  IAPWS-IF97 wet steam region: t = 0 °C ... t = 373.946 °C
  p = 0.000611 MPa ... p = 22.064 MPa

  → Press <ENTER> only, because in the example the state point is located in the single-phase region.

  Now the calculation starts during which the BUSY-symbol is displayed.

- After the calculation has been finished the result for *h* in kJ/kg is displayed:

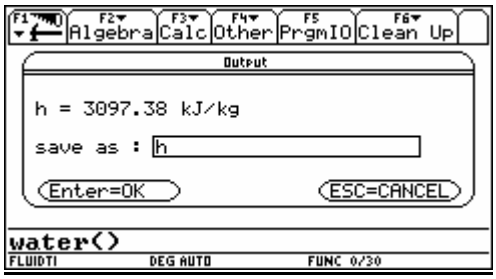


  → In the example, the function calculation results in 3097.38 kJ/kg.

- The calculation of *h* = f(*p*,*t*,*x*) is now complete.

The calculated value for *h* can be saved as a variable and used in other calculations with the pocket computer.

→ E.g.: Enter the variable name "h" into the "save as:" window and press <ENTER> twice:



Consequently, the variable h can be used in the folder "FLUIDTI".

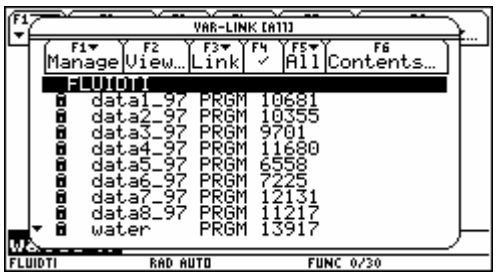
Note.
For the variable any name can be chosen, except for those which start with the ω (Omega)-symbol and system variables (cf. TI Handbook).
In general, variables beginning with the ω-symbol must not be used within the "FLUIDTI" folder.

- The FluidTI main menu is displayed again.
- Press <ESC> to leave FluidTI or start a new calculation.

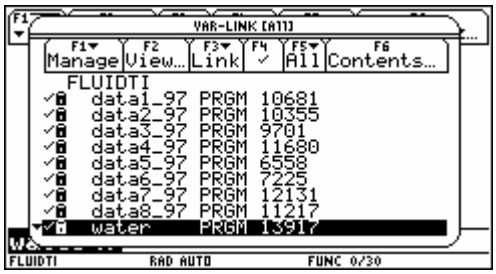
3.3 Uninstalling FluidTI

Please carry out the following steps:

1. Open the menu "Var-Link" by pressing <2nd>, and < - > (not <(-)>).
   The following menu will be displayed:

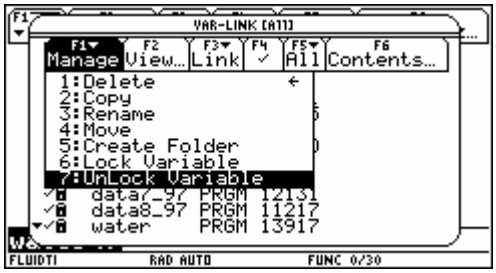


2. Move the cursor to "FLUIDTI". The following files belong to this folder.
   Move the cursor to the file "data1_97" and select it with <F4>. A check mark is situated in front of this file.



   Repeat the selecting procedure with the files "data2_97" down to "data8_97", and "water".

3. Press <F1>. The "Manage" menu is displayed.
   Move the cursor to "UnLock Variable" and press <ENTER>:



4. In order to delete the files press <F1>. The "Manage" menu arises for the second time.
   Move the cursor to "Delete" and press <ENTER>.
   Press again <ENTER> in the following menu.
5. Press <ESC> to leave the "Var-Link" menu.

FluidTI has been removed successfully.

4. Program Documentation

Saturation Pressure $p_S = f(t)$

Name in FluidTI: ps_t_97

Input

t - Temperature t in °C

Output

ps(t) - Saturation pressure p_S in MPa

Range of validity

from t_t = 0 °C up to t_c = 373.946 °C

Response on faulty input values

Error message "Out of Range!" for the following input values:

t < 0 °C or t > 373.946 °C

References: [1], [2], [3], [4], [5]

Saturation Temperature $t_S = f(p)$

Name in FluidTI: ts_p_97

Input

p - Pressure of p in MPa

Output

ts(p) - Saturation temperature t_s in °C

Range of validity

from p_t = 0.000611 MPa up to p = 22.064 MPa

Response on faulty input values

Error message "Out of Range!" for the following input values:

p < 0.000611 MPa or p > 22.064 MPa

References: [1], [2], [3], [4], [5]

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

Name in FluidTI: v_ptx_97

Input

p - Pressure *p* in MPa
t - Temperature *t* in °C
x - Vapor fraction *x* in (kg saturated steam)/(kg wet steam)

Output

v(p,t,x) - Specific volume *v* in m^3/kg

Range of validity

Liquid region: p= p_s(t)...100 MPa at 0 °C...350 °C

Steam region: 0.000611 MPa...p=p_s(t) at 0 °C...350 °C
0.000611 MPa...p_{23}(t) = p(s=5.2 kJ/(kg K)) at 350 °C... 590 °C
0.000611 MPa...100 MPa at 590 °C... 800 °C

Comment on the vapor fraction *x* and calculations for wet steam

The subprograms automatically deal with the wet steam region. For this purpose the following specifications for the vapor fraction *x* are to be regarded:

- If the state point to be calculated is located within the single-phase region (of liquid or superheated steam) enter the value x = - 1. Pressure *p* and temperature *t* are given.
- When calculating wet steam the value of x to be entered ranges from 0 to 1 (in case of boiling liquid: x = 0; in case of saturated vapor: x = 1).

  In the case of wet steam it is adequate to put in either the value given for t and p = -1, or the given value for p and t = -1, as well as the value for *x* which ranges from 0 to 1.

  If you enter *p* and *t* and *x* when calculating wet steam, the program considers *p* and *t* to meet the vapor-pressure curve. If this does not apply, the selected function to be calculated results in -1.

Wet steam region: t = 0 °C ... 350 °C
p = 0.000611 MPa ... 16.5292 MPa

Response on faulty input values

Error message "Out of Range!" for the following input values:

Single-phase region: (x = -1) the parameters entered are located outside the above mentioned range of validity

Wet steam region:
($0 \le x \le 1$) at t = -1 and p > 16.5292 MPa or p < 0.000611 MPa or
at p > 16.5292 MPa or p < 0.000611 MPa
and t > 350° C or t < 0° C
at $| t-t_s(p) | > 0.1$ K

References: [1], [2], [3], [4], [5]

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

Name in FluidTI: h_ptx_97

Input

p - Pressure *p* in MPa
t - Temperature *t* in °C
x - Vapor fraction *x* in (kg saturated steam)/(kg wet steam)

Output

h(p,t,x) - Specific enthalpy *h* in kJ/kg

Range of validity

Liquid region:	$p = p_s(t)$...100 MPa at 0 °C...350 °C
Steam region:	0.000611 MPa...$p=p_s(t)$ at 0 °C...350 °C
	0.000611 MPa...$p_{23}(t) = p(s=5.2$ kJ/(kg K)) at 350 °C... 590 °C
	0.000611 MPa...100 MPa at 590 °C... 800 °C

Comment on the vapor fraction *x* and calculations for wet steam

The subprograms automatically deal with the wet steam region. For this purpose the following specifications for the vapor fraction *x* are to be regarded:

- If the state point to be calculated is located within the single-phase region (of liquid or superheated steam) enter the value x = - 1. Pressure *p* and temperature *t* are given.
- When calculating wet steam the value of *x* to be entered ranges from 0 to 1 (in case of boiling liquid: x = 0; in case of saturated vapor: x = 1).

  In the case of wet steam it is adequate to put in either the value given for t and p = -1, or the given value for p and t = -1, as well as the value for *x* which ranges from 0 to 1.

  If you enter *p* and *t* and *x* when calculating wet steam, the program considers *p* and *t* to meet the vapor-pressure curve. If this does not apply, the selected function to be calculated results in -1.

Wet steam region: t = 0 °C ... 350 °C
p = 0.000611 MPa ... 16.5292 MPa

Response on faulty input values

Error message "Out of Range!" for the following input values:

Single-phase region: ($x = -1$)	the parameters entered are located outside the above mentioned range of validity
Wet steam region: ($0 \le x \le 1$)	at $p = -1$ and $t > 350$° C or $t < 0$° C or at $t = -1$ and $p > 16.5292$ MPa or $p < 0.000611$ MPa or at $p > 16.5292$ MPa or $p < 0.000611$ MPa and $t > 350$° C or $t < 0$° C at $\lvert t-t_s(p) \rvert > 0.1$ K

References: [1], [2], [3], [4], [5]

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

Name in FluidTI: s_ptx_97

Input

p - Pressure p in MPa
t - Temperature t in °C
x - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Output

s(p,t,x) - Specific entropy s in kJ/(kg K)

Range of validity

Liquid region: $p = p_S(t)$...100 MPa for 0 °C...350 °C
Steam region: 0.000611 MPa...$p = p_S(t)$ for 0 °C...350 °C
0.000611 MPa...$p_{23}(t) = p(s=5.2$ kJ/(kg K)) for 350 °C... 590 °C
0.000611 MPa...100 MPa for 590 °C... 800 °C

Comment on the vapor fraction *x* and calculations for wet steam

The subprograms automatically deal with the wet steam region. For this purpose the following specifications for the vapor fraction x are to be regarded:

- If the state point to be calculated is located within the single-phase region (of liquid or superheated steam) enter the value x = - 1. Pressure p and temperature t are given.
- When calculating wet steam the value of x to be entered ranges from 0 to 1 (in case of boiling liquid: x = 0; in case of saturated vapor: x = 1).

  In the case of wet steam it is adequate to put in either the value given for t and p = -1, or the given value for p and t = -1, as well as the value for x which ranges from 0 to 1.

  If you enter p and t and x when calculating wet steam, the program considers p and t to meet the vapor-pressure curve. If this does not apply, the selected function to be calculated results in -1.

Wet steam region: t = 0 °C ... 350 °C
p = 0.000611 MPa ... 16.5292 MPa

Response on faulty input values

Error message "Out of Range!" for the following input values:

Single-phase region ($x = -1$): the parameters entered are located outside the above mentioned range of validity

Wet steam region ($0 \le x \le 1$): at $p = -1$ and $t > 350$° C or t < 0° C or
at $t = -1$ and $p > 16.5292$ MPa or $p < 0.000611$ MPa or
at $p > 16.5292$ MPa or $p < 0.000611$ MPa
and $t > 350$° C or $t < 0$° C
at $| t - t_S(p) | > 0.1$ K

References: [1], [2], [3], [4], [5]

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

Name in FluidTI: t_ph_97

Input

p - Pressure p in MPa
h - Specific enthalpy h in kJ/kg

Output

t(p,h) - Temperature t in °C

Range of validity

Liquid region:	IAPWS-IF97 region 1 (Figure 1)
Steam region:	IAPWS-IF97 region 2 (Figure 1)
Wet steam region:	p = 0.000611 ... 16.5292 MPa and h'(p) < h < h"(p)

Comment on the calculations for wet steam

The subprogram automatically calculates the wet steam region. That is, the program checks, with reference to the given values of p and h, whether the state point to be calculated is located in the single-phase region (liquid or steam) or the wet steam region. The calculation is carried out for the appropriate region.

Response on faulty input values

Error message "Out of Range!" for the following input values:

Liquid region:	at values of p and h beyond the IAPWS-IF97 region 1 (Figure 1)
Steam region:	at values of p and h beyond the IAPWS-IF97 region 2 (Figure 1)
Wet steam region:	at values of $p > 16.5292$ MPa or $p < 0.000611$ MPa

References: [1], [2], [3], [4], [5]

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

Name in FluidTI: t_ps_97

Input

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

Output

t(p,s) - Temperature *t* in °C

Range of validity

Liquid region:	IAPWS-IF97 region 1 (Figure 1)
Steam region:	IAPWS-IF97 region 2 (Figure 1)
Wet steam region:	p = 0.000611 ... 16.5292 MPa

Comment on the calculations for wet steam

The subprogram automatically calculates the wet steam region. That is, the program checks, with reference to the given values of *p* and *h*, whether the state point to be calculated is located in the single-phase region (liquid or steam) or the wet steam region. The calculation is carried out for the appropriate region.

Response on faulty input values

Error message "Out of Range!" for the following input values:

Liquid region:	at values of *p* and *s* beyond the IAPWS-IF97 region 1 (Figure 1)
Steam region:	at values of *p* and *s* beyond the IAPWS-IF97 region 2 (Figure 1)
Wet steam region:	at values of $p > 16.5292$ MPa or $p < 0.000611$ MPa

References: [1], [2], [3], [4], [5]

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

Name in FluidTI: x_ph_97

Input

p - Pressure p in MPa
h - Specific enthalpy h in kJ/kg

Output

x(p,h) - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Range of validity

Liquid region:	IAPWS-IF97 region 1 (Figure 1)
Steam region:	IAPWS-IF97 region 2 (Figure 1)
Wet steam region:	p = 0.000611 ... 16.5292 MPa and h'(p) < h < h"(p)

Comment on the calculations for wet steam

The subprogram automatically calculates the wet steam region. That is, the program checks, with reference to the given values of p and h, whether the state point to be calculated is located in the single-phase region (liquid or steam) or the wet steam region. In case of wet steam the value of x is calculated. If the state point to be calculated is located in the single-phase region the vapor fraction result is x = -1.

Response on faulty input values

If the state point to be calculated is located in the single-phase region the result x(p,h) = -1 is displayed for the following input values:

$p > 16.5292$ MPa or $h < h'(p)$ or $h > h''(p)$

Error message "Out of Range!" for the following input values:
$p < 0.000611$ MPa or $p > 100$ MPa

References: [1], [2], [3], [4], [5]

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

Name in FluidTI: x_ps_97

Input

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

Output

x(p,s) - Vapor fraction *x* in (kg saturated steam)/(kg wet steam)

Range of validity

Liquid region:	IAPWS-IF97 region 1 (Figure 1)
Steam region:	IAPWS-IF97 region 2 (Figure 1)
Wet steam region:	p = 0.000611 ... 16.5292 MPa and s'(p) < s < s''(p)

Comment on the calculations for wet steam

The subprogram automatically calculates the wet steam region. That is, the program checks, with reference to the given values of *p* and *h*, whether the state point to be calculated is located in the single-phase region (liquid or steam) or the wet steam region. In case of wet steam the value of *x* is calculated. If the state point to be calculated is located in the single-phase region the vapor fraction result is x = -1.

Response on faulty input values

If the state point to be calculated is located in the single-phase region the result x(p,h) = -1 occurs for the following input values:

$p > 16.5292$ MPa or $s < s'(p)$ or $s > s''(p)$

Error message "Out of Range!" for the following input values:
$p < 0.000611$ MPa or $p > 100$ MPa

References: [1], [2], [3], [4], [5]

Dynamic Viscosity η = f(*p*,*t*,*x*)

Name in FluidTI: eta_ptx_97

Input

p - Pressure *p* in MPa
t - Temperature *t* in °C
x - Vapor fraction *x* in (kg saturated steam)/(kg wet steam)

Output

η(p,t,x) - Dynamic viscosity η in MPa s

Range of validity

Liquid region:	p= p_S(t)...100 MPa for 0 °C...350 °C
Steam region:	0.000611 MPa...p=p_S(t) for 0 °C...350 °C
	0.000611 MPa...p_{23}(t) = p(s=5.2 kJ/(kg K)) for 350 °C... 590 °C
	0.000611 MPa...100 MPa for 590 °C... 800 °C

Comment on the vapor fraction *x* and calculations for wet steam

The subprograms automatically deal with the wet steam region. For this purpose the following specifications for the vapor fraction *x* are to be regarded:

- If the state point to be calculated is located within the single-phase region (of liquid or superheated steam) enter the value x = - 1. Pressure *p* and temperature *t* are given.
- When calculating wet steam the value of *x* to be entered ranges from 0 to 1 (in case of boiling liquid: x = 0; in case of saturated vapor: x = 1).

  In the case of wet steam it is adequate to put in either the value given for t and p = -1, or the given value for p and t = -1, as well as the value for *x* which ranges from 0 to 1.

  If you enter *p* and *t* and *x* when calculating wet steam, the program considers *p* and *t* to meet the vapor-pressure curve. If this does not apply, the selected function to be calculated results in -1.

Saturated liquid and saturated vapor:	t = 0 °C ... 350 °C
	p = 0.000611 MPa ... 16.5292 MPa

Response on faulty input values

Error message "Out of Range!" for the following input values:

Single-phase region: (*x* = -1)	the parameters entered are located outside the above mentioned range of validity
Saturated liquid and saturated vapor: (*x* = 0 or *x* = 1)	at *p* = -1 and *t* > 350° C or *t* < 0° C or at *t* = -1 and *p* > 16.5292 MPa or *p* < 0.000611 MPa or at *p* > 16.5292 MPa or *p* < 0.000611 MPa and *t* > 350° C or *t* < 0° C at | *t*-t_S(*p*) | > 0.1 K

References: [7], internal calculation of ρ or v: [1], [2], [3], [4], [5]

Thermal Conductivity λ = f(*p*,*t*,*x*)

Name in FluidTI: lambda_ptx_97

Input

p - Pressure *p* in MPa
t - Temperature *t* in °C
x - Vapor fraction *x* in (kg saturated steam)/(kg wet steam)

Output

lam(p,t,x) - Thermal conductivity λ in W/(m K)

Range of validity

Liquid region: p= p_s(t)...100 MPa for 0 °C...350 °C
Steam region: 0.000611 MPa...p=p_s(t) for 0 °C...350 °C
0.000611 MPa...p_{23}(t) = p(s=5.2 kJ/(kg K)) for 350 °C... 590 °C
0.000611 MPa...100 MPa for 590 °C... 800 °C

Comment on the vapor fraction *x* and calculations for wet steam

The subprograms automatically deal with the wet steam region. For this purpose the following specifications for the vapor fraction *x* are to be regarded:

- If the state point to be calculated is located within the single-phase region (of liquid or superheated steam) enter the value x = - 1. Pressure p and temperature t are given.
- When calculating wet steam the value of *x* to be entered ranges from 0 to 1 (in case of boiling liquid: x = 0; in case of saturated vapor: x = 1).

  In the case of wet steam it is adequate to put in either the value given for t and p = -1, or the given value for p and t = -1, as well as the value for *x* which ranges from 0 to 1.

  If you enter *p* and *t* and *x* when calculating wet steam, the program considers *p* and *t* to meet the vapor-pressure curve. If this does not apply, the selected function to be calculated results in -1.

Saturated liquid and saturated vapor: t = 0 °C ... 350 °C
p = 0.000611 MPa ... 16.5292 MPa

Response on faulty input values

Error message "Out of Range!" for the following input values:

Single-phase region: (x = -1) the parameters entered are located outside the above mentioned range of validity

Saturated liquid and saturated vapor: (x = 0 or x = 1)
at p = -1 and t > 350° C or t < 0° C or
at t = -1 and p > 16.5292 MPa or p < 0.000611 MPa or
at p > 16.5292 MPa or p < 0.000611 MPa
and t > 350° C or t < 0° C
at | t-t_s(p) | > 0.1 K

References: [7], internal calculation of ρ or v: [1], [2], [3], [4], [5]

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

Name in FluidTI: cp_ptx_97

Input

p - Pressure p in MPa
t - Temperature t in °C
x - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Output

cp(p,t,x) - Specific isobaric heat capacity c_p in kJ/kg K

Range of validity

Liquid region:	p= p_s(t)...100 MPa at 0 °C...350 °C
Steam region:	0.000611 MPa...p=p_s(t) at 0 °C...350 °C
	0.000611 MPa...p_{23}(t) = p(s=5.2 kJ/(kg K) at 350 °C... 590 °C
	0.000611 MPa...100 MPa at 590 °C... 800 °C

Comment on the vapor fraction *x* and calculations for wet steam

The subprograms automatically deal with the wet steam region. For this purpose the following specifications for the vapor fraction x are to be regarded:

- If the state point to be calculated is located within the single-phase region (of liquid or superheated steam) enter the value x = - 1. Pressure p and temperature t are given.
- When calculating wet steam the value of x to be entered ranges from 0 to 1 (in case of boiling liquid: x = 0; in case of saturated vapor: x = 1).

  In the case of wet steam it is adequate to put in either the value given for t and p = -1, or the given value for p and t = -1, as well as the value for x which ranges from 0 to 1.

  If you enter p and t and x when calculating wet steam, the program considers p and t to meet the vapor-pressure curve. If this does not apply, the selected function to be calculated results in -1.

Saturated liquid and saturated vapor: t = 0 °C ... 350 °C
p = 0.000611 MPa ... 16.5292 MPa

Response on faulty input values

Error message "Out of Range!" for the following input values:

Single-phase region: (x = -1)	the parameters entered are located outside the above mentioned range of validity
Saturated liquid and saturated vapor: (x = 0 or x = 1)	at p = -1 and t > 350° C or t < 0° C or at t = -1 and p > 16.5292 MPa or p < 0.000611 MPa or at p > 16.5292 MPa or p < 0.000611 MPa and t > 350° C or t < 0° C at | t-t_s(p) | > 0.1 K

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