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

FluidTI

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

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Contents

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1. Property Functions for Water and Steam

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

Functional Dependence	**Name in FluidTI**	**Property or Function**	**Unit of the Result**
$p_S = f(t)$	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	$Pa \cdot s = kg/m \cdot s$
$\lambda = f(p,t,x)$	lambda_ptx_97	Heat 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: Regions 1, 2 and 3 of the IAPWS-IF97 including wet steam

Pressure: from 0.000611 MPa up to 100 MPa
Temperature: from 0 °C up to 800 °C

Hints for Wet Steam and Vapor Fraction x

The subprograms handle the wet steam region automatically. The following cautions, regarding to the value of the vapor fraction x, should be noted:

In case the point of state to be calculated is situated in the single phase regions, liquid or superheated vapor, no input or the value -1 has to be entered for x. The backward functions will give the value x = -1 as a result in this case.

In case the point of state to be calculated is situated in the two phase region (wet steam), values between 0 and 1 have to be entered for x (the value x = 0 for saturated liquid, the value x = 1 for saturated vapor). The backward functions will give values between 0 and 1 as results for x.

In case the point of state to be calculated is situated in the two phase region either the given value for t and no input for p (or p = -1) or the given value for p and no input for t (or t = -1) and in both cases the value for x between 0 and 1 has to be entered.

In case of wet steam, p and t and x are entered as given values, the program tests whether p and t fulfill the saturation line. If it is not true, an error message appears.

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

Attention !

If the input values lie outside the range of validity of the IAPWS-IF97 or they do not fit together, an error message appears.

2. Range of Validity and Structure of the Program FluidTI

The International Association for the Properties of Water and Steam IAPWS issued the

"Release on the IAPWS Industrial Formulation 1997
for the Thermodynamic Properties of Water and Steam IAPWS-IF97"

in September 1997 [1], [2], [3]. It will be abbreviated as IAPWS-IF97. This new industrial standard has to be used in acceptance and guarantee calculations of facilities and plants working with water or steam worldwide. The IAPWS-IF97 Formulation replaces the former Industrial Formulation IFC-67 [12].

Figure 1 shows the entire range of validity of the equation set of the new Industrial Formulation IAPWS-IF97. It covers temperatures from 0 °C up to 800 °C for pressures from 0.000611 up to 100 MPa and temperatures up to 2000 °C for pressures up to 10 MPa.

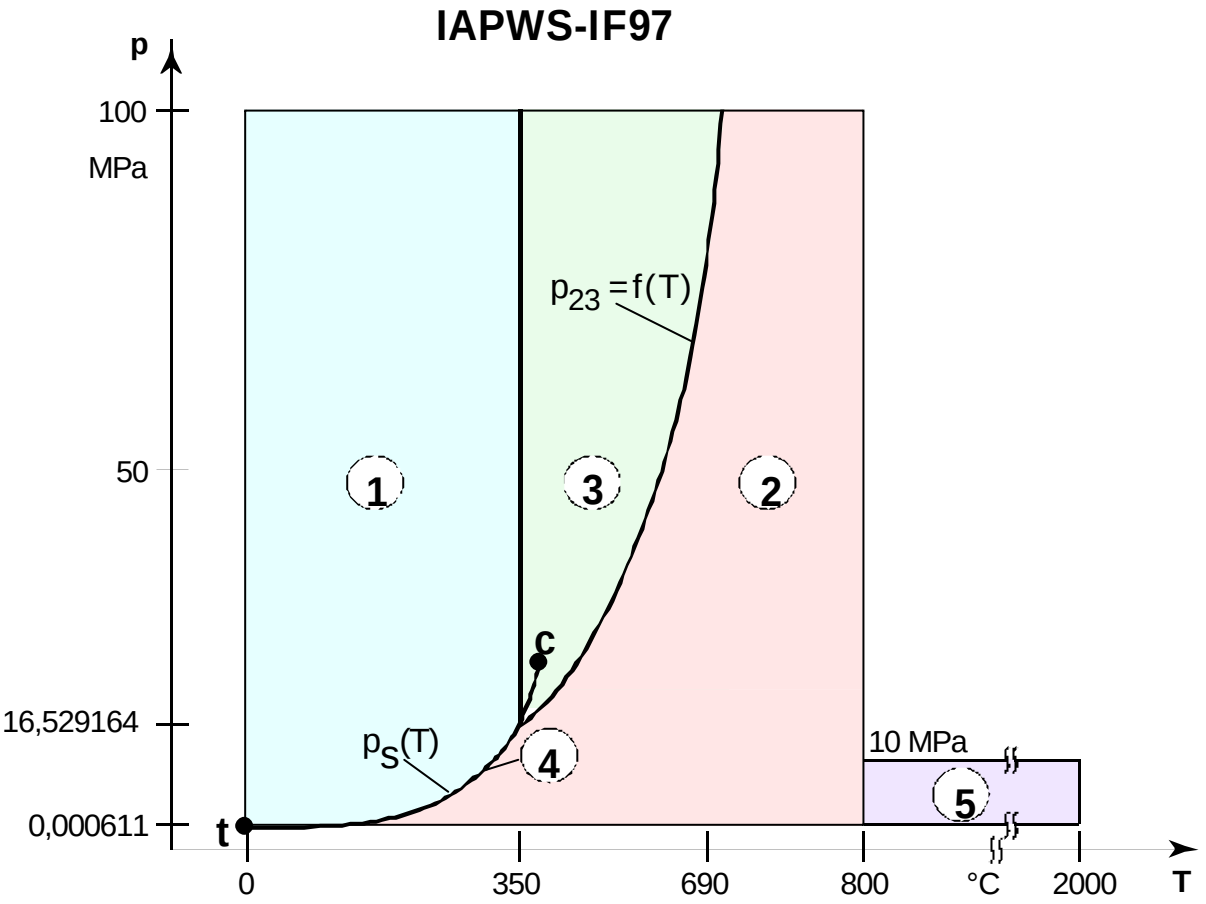


Figure 1: Entire Range of Validity of the IAPWS-IF97

The entire range of validity is divided into five calculation regions. Each of the calculation regions contains its own equations of state. They are described in detail in the official Release of the IAPWS [1] and in the publications by *Wagner et al.* [2] and [3].

The present version of FluidTI cannot be used in the entire range of validity. Calculations are possible in region 1 and 2 and wet steam region until pressure 16.529164 MPa (figure1).
Calls to the necessary equation for each calculation region are incorporated within the program.

3. Using FluidTI for Calculation of Water and Steam

3.1 Installation of FluidTI on TI 89, TI 92, TI 92Plus, and TI voyage 200

The program FluidTI will be copied from the PC to the calculator using a special Link Program and the appropriate Link Cable.

The Link Program can received from a service partner of Texas Instruments® or downloaded from the TI web site: http://www.ti.com/calc/docs/link.htm. The Link Cable can be received from the service partner too.

The following description is related to the Link Programs

TI-Graph-Link® and TI-Connect®,

which should already have been installed at the PC.

(In case another Link Program will be used, the procedure for the file transfer has to be taken from the corresponding user guide or online-help.)

1. Insert the CD FluidTI into the PC. 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 with the PC by using the serial link cable or the USB cable.
   In case of you will use the link program TI-Connect® for data transfer please follow Paragraph 4.

3. Data Transfer with TI-Graph-Link â

Start the program TI-Graph-Link® on PC.

Open the "Link" menu and click "Send..." .

Choose your CD drive in the window "Drives".

In the window "File Name:" the Group File name(s) related to the connected model is displayed.
Note, two Group Files are available for TI 92 (see Table above).

The file IF97_voyage_200.9xg for voyage 200 is shown as IF97_v~1.9xg.

Click the right name belonging to your TI model and than click the button "Add".

Now in the lower window "Files Selected:", the Group File name including the CD drive is shown.

Mark "Retain Folder".

Make shore the TI calculator is switched on.

Then click "OK" to send the files to TI calculator. A window on PC displays the list of the files received by the TI.

After completion of the file transfer, click "OK" to return to the desktop.

The installation of FluidTI on the calculator was finished.

In case the file transfer did not work, there are some possibilities of mistakes:

- The TI was not connected to the PC or not switched on when starting TI-Graph-Link®.
- The wrong communication port was selected (COM 1 ... COM 2 in menu "Link").
- The cursor of the TI was not in the command line when starting file transfer.
- A wrong link cable was used or selected in the menu "Cable type".
- The Link Cable was not inserted correctly.

4. Data Transfer with TI-Connect â

Make shore the TI calculator is switched on.

Start the program TI-Connect® on PC.

Click on "TI DeviceExplorer".

In certain cases, the menu "TI Communication Settings" is opened.

The name of the TI calculator, the cable name and the used port for the cable are listed. Check the correctness and confirm by clicking the button "OK".

Now, TI-Connect® search access to the TI calculator.

After finding access, the directory tree of the connected TI calculator is shown.

Click in the upper menu bar on "tools" and then on "TI GroupExplorer".

Search the letter of your CD drive and click on "+" next to it.

The group files are shown below.

Click on the file that belongs to your TI model (see Table above).

Then, click on this file by using the right mouse button. The context menu arises.

Click on "Send To Device".

The data transfer from the PC to the TI calculator starts. The copied files are shown on a window on PC.

The directory FLUIDTI has been created on the TI calculator and the program files have been copied in this directory.

In case the file transfer did not work, there are some possibilities of mistakes:

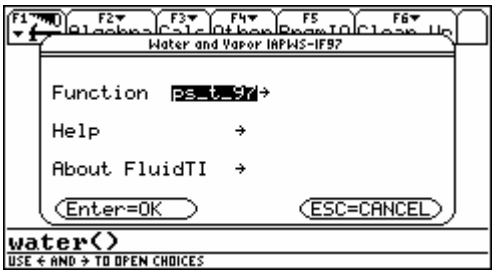
- The TI was not connected to the PC or not switched on when starting TI-Connect®.
- The cursor of the TI was not in the command line when starting file transfer.
- A wrong link cable was used.
- The Link Cable was not inserted correctly.

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

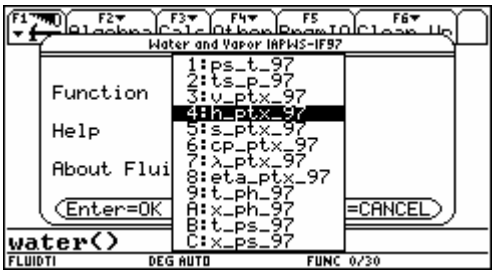
The specific enthalpy h should be calculated from given pressure p, given temperature t and given vapour fraction x for steam using the Industrial-Formulation IAPWS-IF97 [1,2,3] on TI 89, TI 92, TI 92Plus, or TI voyage 200.

Complete the following steps :

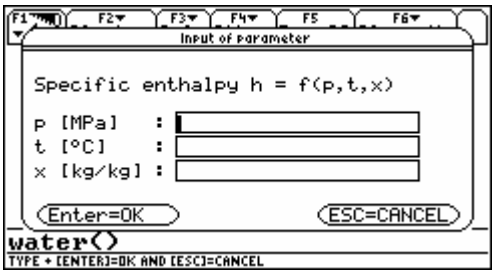
- Press <MODE> and move the cursor to "Current Folder...".
  Move the cursor right, choose "fluidti" and press <ENTER>.
  Now, "fluidti" flashes in the field "Current Folder".
  Press again <ENTER>. "FLUIDTI" arises in the lower left corner of the screen.
- Now, enter "water()" in the command line and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



  and the property function "ps_t_97" is flashing.
- Move the cursor right to open menu "Function".
  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" is flashing now. Press <ENTER>.
- The following menu "Input of parameters" arises:



- Enter the given value for p in MPa into the belonging window. Pay attention to the range of validity of the IAPWS-IF97:

  p = 0.000611 MPa ... 100 MPa.

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

- Enter the given value for t in °C into the belonging window. Pay attention to the range of validity of the IAPWS-IF97:

  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) has to be entered into the belonging window. The following cautions should be noted:

  The subprograms handle the wet steam region automatically.

  In case the point of state to be calculated is situated in the single phase regions, liquid or superheated vapor, no input or the value -1 has to be entered for x. The backward functions will give the value x = -1 as a result in this case.

  In case the point of state to be calculated is situated in the two phase region (wet steam), values between 0 and 1 have to be entered for x (the value x = 0 for saturated liquid, the value x = 1 for saturated vapor). The backward functions will give values between 0 and 1 as results for x.

  In case the point of state to be calculated is situated in the two phase region either the given value for t and no input for p (or p = -1) or the given value for p and no input for t (or t = -1) and in both cases the value for x between 0 and 1 has to be entered.

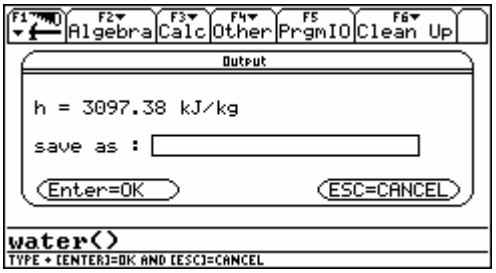
  In case of wet steam, p and t and x are entered as given values, the program tests whether p and t fulfill the saturation line. If it is not true, an error message appears.

  Wet steam region of the IF97: t = 0 °C ... t = 373.946 °C
  p = 0.000611 MPa ... p = 22.064 MPa

  → Press only <ENTER> because the state of point is situated in the single phase region in the example.

  Now, the calculation begins. While calculating the BUSY-symbol is shown.

- After finishing the result for h in kJ/kg is shown at the display:

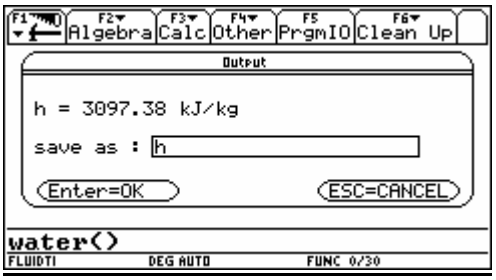


  → In the example, the value 3097.38 kJ/kg should arise.

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

The calculated value for h can be stored into a variable for using in other calculations on the pocket computer.

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



The variable h can be used in the folder "FLUIDTI" after that.

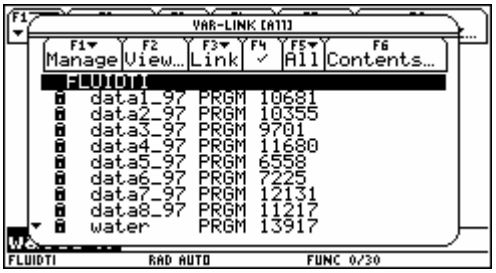
Hint: Any name for the variable can be chosen except beginning with the symbol w (Omega) and being a system variable (compare TI Handbook).
In general, variables beginning with the symbol w need not being used within the folder "FLUIDTI".

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

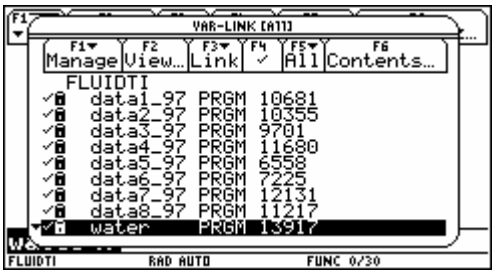
3.3 Removing FluidTI

The following steps must be completed:

1. Open the menu "Var-Link" by pressing <2nd> and afterwards < - > (not <(-)>).
   The following menu arises:

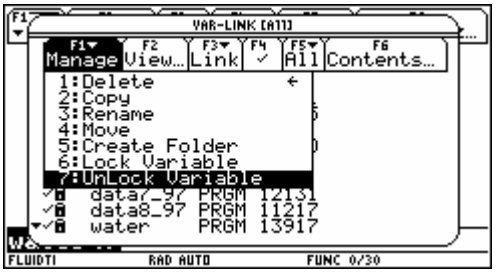


2. Move the cursor to "FLUIDTI" . The following files belong to this folder.
   Move the cursor to the file "data1_97" and mark it with <F4>. A check-mark is situated in front of this file.



   Repeat this marking procedure with the files "data2_97" to "data8_97" and "water".

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



4. To delete the files press <F1>. The menu "Manage" 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 menu "Var-Link".

4. Program Documentation for Water and Steam

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 = 0 °C to t = 373.946 °C

Reaction for wrong input

Error message "Out of Range!" for 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 = 0.000611 MPa to p = 22.064 MPa

Reaction for wrong input

Error message "Out of Range!" for 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 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

Because wet steam is handled automatically, the following cautions regarding the input value of the vapor fraction x should be noted:

When the point to be calculated is in the single phase regions (liquid or superheated vapor), the pressure p and temperature t are given and the value -1 has to be entered for x.

When the point to be calculated is in wet steam, values between 0 and 1 have to be entered for x (the value 0 for saturated liquid, the value 1 for saturated vapor).

For wet steam, either the given value for t and p = -1 or the given value for p and t = -1 and (in both cases) the value for x between 0 and 1 have to be entered. For wet steam, if p and t and x are entered, the program tests whether p and t correspond to the saturation line. If this is not true, the calculated property will be -1.

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

Reaction for wrong input

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

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

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 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

Because wet steam is handled automatically, the following cautions regarding the input value of the vapor fraction x should be noted:

When the point to be calculated is in the single phase regions (liquid or superheated vapor), the pressure p and temperature t are given and the value -1 has to be entered for x.

When the point to be calculated is in wet steam, values between 0 and 1 have to be entered for x (the value 0 for saturated liquid, the value 1 for saturated vapor).

For wet steam, either the given value for t and p = -1 or the given value for p and t = -1 and (in both cases) the value for x between 0 and 1 have to be entered. For wet steam, if p and t and x are entered, the program tests whether p and t correspond to the saturation line. If this is not true, the calculated property will be -1.

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

Reaction for wrong input

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

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

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 MP a 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 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

Because wet steam is handled automatically, the following cautions regarding the input value of the vapor fraction x should be noted:

When the point to be calculated is in the single phase regions (liquid or superheated vapor), the pressure p and temperature t are given and the value -1 has to be entered for x.

When the point to be calculated is in wet steam, values between 0 and 1 have to be entered for x (the value 0 for saturated liquid, the value 1 for saturated vapor).

For wet steam, either the given value for t and p = -1 or the given value for p and t = -1 and (in both cases) the value for x between 0 and 1 have to be entered. For wet steam, if p and t and x are entered, the program tests whether p and t correspond to the saturation line. If this is not true, the calculated property will be -1.

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

Reaction for wrong input

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

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

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 wet steam region is handled automatically. This means with reference to the given values for p and h a subroutine find out whether the condition point to be calculated lies in the one phase area (liquid or steam) or in the wet steam region. Then the concerning condition area will be calculated.

Reaction for wrong input

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

Liquid region :	at values of p and h outside region 1 of the IAPWS-IF97 (Figure 1)
Steam region:	at values of p and h outside region 2 of the IAPWS-IF97 (Figure 1)
Water 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 wet steam region is handled automatically. This means with reference to the given values for p and s a subroutine find out whether the condition point to be calculated lies in the one phase area (liquid or steam) or in the wet steam region. Then the concerning condition area will be calculated.

Reaction for wrong input

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

Liquid region :	at values of p and s outside region 1 of the IAPWS-IF97 (Figure 1)
Steam region:	at values of p and s outside region 2 of the IAPWS-IF97 (Figure 1)
Water 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 wet steam region is handled automatically. This means with reference to the given values for p and h a subroutine find out whether the condition point to be calculated lies in the one phase area (liquid or steam) or in the wet steam region. In case of wet steam the value of x will be calculated. Is the condition point to be calculated in a one phase area the result of x will be x = -1.

Reaction for wrong input

Result x(p,h) = -1 for input values:

if the condition point to be calculated lies in the one phase area:
p > 16.5292 MPa or h < h'(p) or h > h''(p)

Error message "Out of Range!" for 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 wet steam region is handled automatically. This means with reference to the given values for p and s a subroutine find out whether the condition point to be calculated lies in the one phase area (liquid or steam) or in the wet steam region. In case of wet steam the value of x will be calculated. Is the condition point to be calculated in a one phase area the result of x will be x = -1.

Reaction for wrong input

Result x(p,s) = -1 for input values:

if the condition point to be calculated lies in the one phase area:
p > 16.5292 MPa or s < s'(p) or s > s''(p)

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

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

Dynamic Viscosity h = 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

h **(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

Because wet steam is handled automatically, the following cautions regarding the input value of the vapor fraction x should be noted:

When the point to be calculated is in the single phase regions (liquid or superheated vapor), the pressure p and temperature t are given and the value -1 has to be entered for x.

When the point to be calculated is in wet steam, values between 0 and 1 have to be entered for x (the value 0 for saturated liquid, the value 1 for saturated vapor).

For wet steam, either the given value for t and p = -1 or the given value for p and t = -1 and (in both cases) the value for x between 0 and 1 have to be entered. For wet steam, if p and t and x are entered, the program tests whether p and t correspond to the saturation line. If this is not true, the calculated property will be -1.

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

Reaction for wrong input

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

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

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

Because wet steam is handled automatically, the following cautions regarding the input value of the vapor fraction x should be noted:

When the point to be calculated is in the single phase regions (liquid or superheated vapor), the pressure p and temperature t are given and the value -1 has to be entered for x.

When the point to be calculated is in wet steam, values between 0 and 1 have to be entered for x (the value 0 for saturated liquid, the value 1 for saturated vapor).

For wet steam, either the given value for t and p = -1 or the given value for p and t = -1 and (in both cases) the value for x between 0 and 1 have to be entered. For wet steam, if p and t and x are entered, the program tests whether p and t correspond to the saturation line. If this is not true, the calculated property will be -1.

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

Reaction for wrong input

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

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

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 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

Because wet steam is handled automatically, the following cautions regarding the input value of the vapor fraction x should be noted:

When the point to be calculated is in the single phase regions (liquid or superheated vapor), the pressure p and temperature t are given and the value -1 has to be entered for x.

When the point to be calculated is in wet steam, values between 0 and 1 have to be entered for x (the value 0 for saturated liquid, the value 1 for saturated vapor).

For wet steam, either the given value for t and p = -1 or the given value for p and t = -1 and (in both cases) the value for x between 0 and 1 have to be entered. For wet steam, if p and t and x are entered, the program tests whether p and t correspond to the saturation line. If this is not true, the calculated property will be -1.

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

Reaction for wrong input

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

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

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

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