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

FluidCASIO LibIF97 for the CFX-9850G and the CFX-9850GB Plus

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

FluidCASIO
LibIF97
for
the CFX-9850G and
the CFX-9850GB Plus

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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0. Package Contents

The "FluidCASIO for the CFX-9850G and the CFX-9850GB Plus" CD includes the following files:

Program files:

BACKTEST.PG	CBACKS1.PG	CBACKS2A.PG	CBACK2B.PG
COEFREG1.PG	COEFREG4.PG	COEFRG2A.PG	COEFRG2B.PG
GAMMA11.PG	GAMMA11A.PG	GAMMA12.PG	GAMMA13.PG
GAMMA1P1.PG	GAMMA1P2.PG	GAMMA1P3.PG	GAMMA1P4.PG
GAMMA1T1.PG	GAMMA1T2.PG	GAMMA1T3.PG	GAMMA21.PG
GAMMA22.PG	GAMMA23.PG	GAMMA24.PG	GAMMA2P1.PG
GAMMA2P2.PG	GAMMA2P3.PG	GAMMA2T1.PG	GAMMA2T2.PG
GAMMA2T3.PG	GAMMA2T4.PG	PS[T].PG	REG1TPS.PG
REG2ATPS.PG	REG2BTPS.PG	REGERROR.PG	REGION1.PG
REGION2.PG	REGTEST.PG	TS[P].PG	WATER-97.PG .

FluidCASIO_CFX-9850G_LibIF97_Docu.pdf - Software documentation

In case the package is shipped, a printed copy will be provided.

1. IAPWS-IF97Functions

Functional Dependence	Function Name in FluidCASIO	Property or Function	Unit
$p_S = f(t)$	ps(t)	Saturation pressure from temperature	MPa
$t_S = f(p)$	ts(p)	Saturation temperature from pressure	°C
$v = f(p,t,x)$	v(p,t,x)	Specific volume	m^3/kg
$h = f(p,t,x)$	h(p,t,x)	Specific enthalpy	kJ/kg
$s = f(p,t,x)$	s(p,t,x)	Specific entropy	kJ/(kg K)
$t = f(p,s)$	t(p,s)	Temperature from pressure and entropy	°C

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

Range of validity: IAPWS-IF97 regions 1 and 2, including wet steam

Liquid region 1: $p = p_s(t)$... 100 MPa for 0 °C...350 °C

Steam region 2: 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 in the single-phase regions (of liquid or superheated vapor) enter -1 as a value of *x*. Pressure *p* and temperature *t* are given.

If the state point to be calculated is located in the wet steam region the value for *x* to be entered ranges from 0 to 1 (0 = saturated liquid, 1 = saturated vapor).

When calculating wet steam it is adequate to enter either the given value for t and p = -1, or the given value for p and t = -1, as well as the value for *x* that 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, an error message is displayed for the selected function to be calculated.

IAPWS-IF97 vapor-pressure curve: t = 0 °C... 350 °C

p = 0.000611 MPa... p_s(t = 350 °C) = 16.5292 MPa

Please note.

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

2. Range of Validity and Program Library 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.

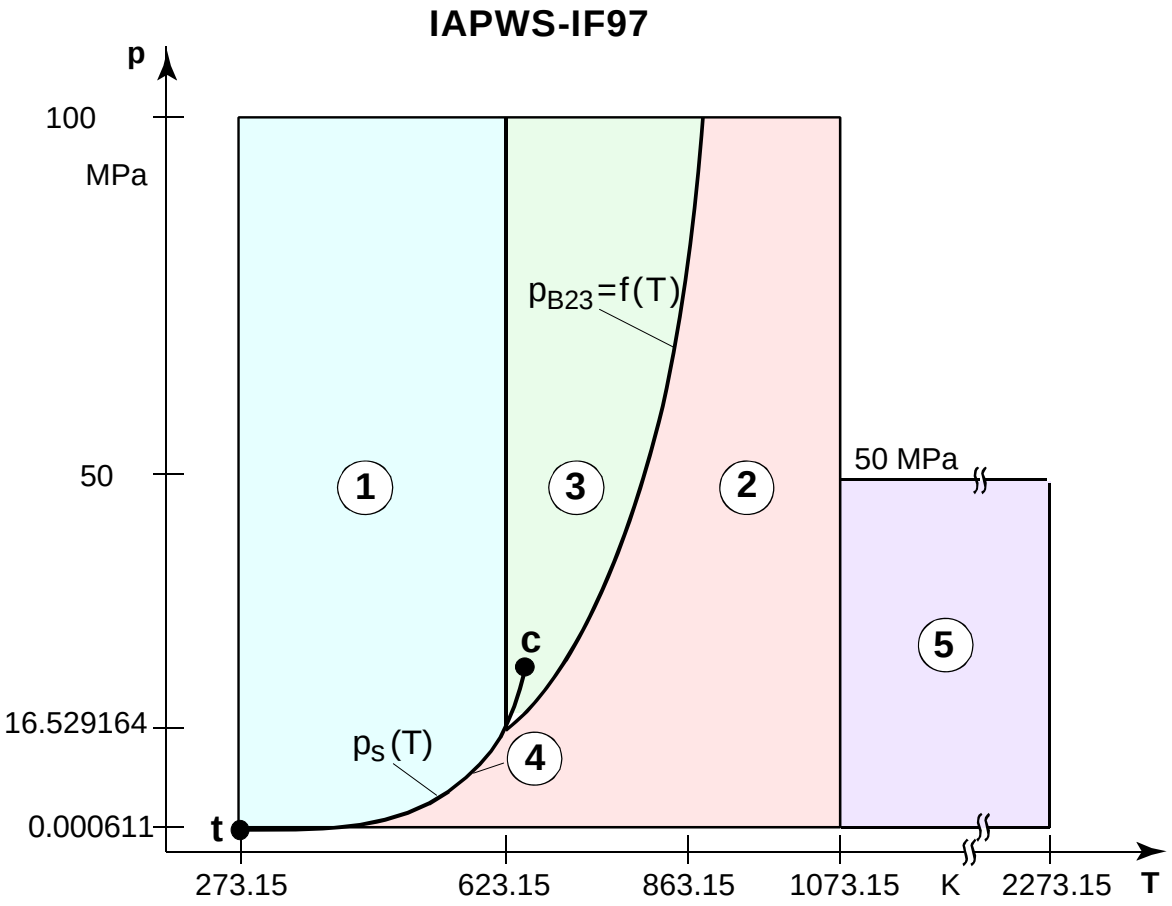


Figure 1: Entire range of validity of the IAPWS-IF97

Internally, the entire range of validity is subdivided into five calculation regions in which apply the appropriate constitutive equations (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 student FluidCASIO 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 FluidCASIO

3.1 Installing FluidCASIO

In order to run the FluidCASIO 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 part of the pocket calculator set. The link cable can be purchased in a specialist shop or at Böttcher Datentechnik GmbH (http://www.boettcher-datentechnik.de/).

The following description refers to the

FX-Link-Kit Connection Software® (link program),

which has to be installed first.

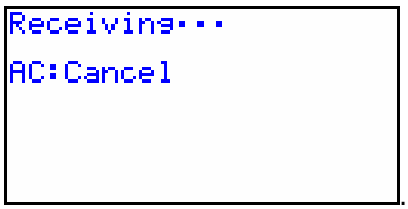
(Instructions for a data transfer relating to other link programs are available in the appropriate online help or software documentation.)

1. Insert the CD "FluidCASIO for the CFX-9850G and the CFX-9850GB Plus" into the CD-ROM drive of your computer.
2. Start the FX-Link-Kit program on your computer.
3. In the Directory Tree window (upper left-hand window), click the CD drive.
   The CD files are displayed in the upper right-hand window.
4. In the Receiving Window (upper right-hand window), click the "  " button (Select All).
   Now, all files should be blue-marked.
5. In this window, click the "  " button.
   All selected files are copied into the Sending Window (lower window).
6. Connect the Casio computer with the PC. Plug the link cable in a free serial interface of the PC (COM1 or COM2), and in the pocket calculator.
7. Switch on the Casio calculator.

   Return to the main menu with the <MENU> key and choose the menu option "LINK" in the lower row of the menu with the help of the cursor block. Confirm with the <EXE> key.

   Now, press the <F2> key.

   The Casio computer is now waiting to receive data. The following screen is displayed:

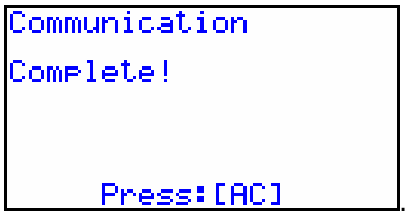


8. In the Sending Window of the FX-Link-Kit program, click the "WATER-97.PG" file and press the "Space" key of the PC keyboard to select the file with a checkmark.

   Then, click the "  "button in the main toolbar of the FX-Link-Kit program.
   A dialog window appears.

   Click "Start" in order to start the transfer.

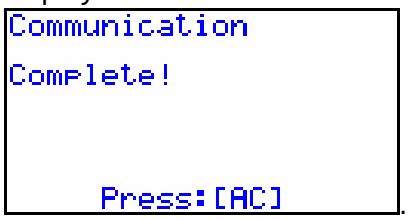
The transfer is complete when the following window is displayed on the Casio calculator:



On the pocket calculator, press the <AC/ON> key and <F2>.

9. Now, check-mark all files except the "WATER-97.PG" file.

Click the "  " button in the main toolbar again and start the transfer by clicking the "Start" button.
The transfer approximately takes 5 minutes. It is complete when the following window is displayed on the calculator:



Press the <AC/ON> key on the pocket calculator.
The FluidCASIO program has been transferred to your pocket calculator. You can return to the main menu pressing the <MENU> key.

Note:

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

- The wrong serial interface and/or the wrong pocket calculator have been preset in the PC link program.
  In order to examine this, click "Program", and then "Options" in the menu bar. Click the "Connection/Calculator" index card in the following window.
  Select the interface in use by clicking the appropriate radio button.
  Then choose "CFX-9850G" or "CFX-9850GB Plus" in the "Calculator" pull-down menu.
  Confirm this by clicking "OK".
- The pocket calculator and the computer have not been connected when the FX-Link-Kit® was started.
- The plugs have not been put in properly.
- An inappropriate or defective link cable has been used.

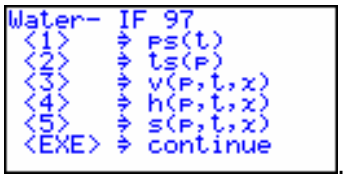
3.2 Example: Calculation of *h* = f(*p*,*t*,*x*)

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.

Carry out the following steps:

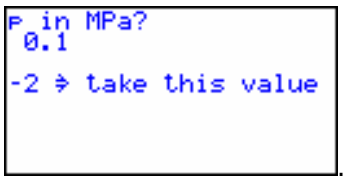
- Press the <MENU> key in order to return to the main menu.
- Start the program choosing the "PRGM" menu option with the help of the cursor block and press the <EXE> key to confirm.

  Using the cursor block, choose the "WATER-97" program file and confirm with <EXE>.
- The following FluidCASIO main menu, including the property functions, is displayed:



  Press <EXE> for further functions:

  Press <EXE> again to return to the first part of the menu.
- In the first menu part, press the key <4> to choose the function "h(p,t,x)".
  The following input window for "pressure p in MPa" is displayed:



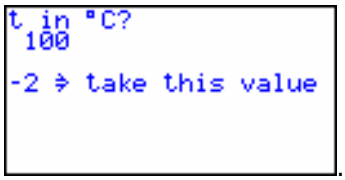
  Consider the IAPWS-IF97 range of validity:

  p= 0.000611 ... 100 MPa.

  → E.g.: Enter the value 10 and confirm your entry by pressing the <EXE> button.

  Note: *Confirm the value displayed in the second line by entering -2.*

  The input window for "temperature t in °C" is displayed:

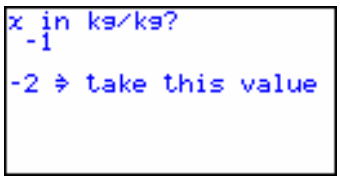


  Consider the IAPWS-IF97 range of validity:

  t = 0 °C ... 800 °C

  → E.g.: Enter the value 400 and confirm your entry by pressing the <EXE> button.

The input window for "vapor fraction x in (kg saturated steam)/(kg wet steam)" is displayed:



Since the subprograms automatically deal with the wet steam region the following specifications for the vapor fraction *x* have to be considered:

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* that ranges from 0 to 1.

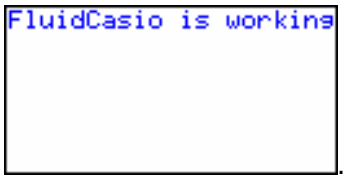
If you enter *p* and *t* and *x* when calculating wet steam, the program considers *p* and *t* to meet the vapor-pressure curve. If this does not apply, the selected function to be calculated results in -1.

Wet steam region: t = 0 °C ... 350 °C

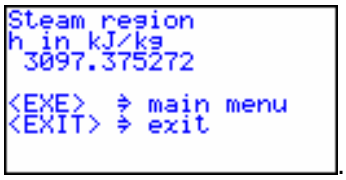
p = 0.000611 MPa ... 16.5292 MPa

→ The state point to be calculated is located in the single-phase region. Therefore, enter x = -1.

- During the calculation the following window is displayed:



- After the calculation the result of "h in kJ/kg" is displayed:



→ In the example, the calculation results in 3097.375274.

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

Note: The value calculated for *h* has been saved as the variable "Γ" (gamma).

Afterwards, this variable can be used independently of FluidCASIO.

In the next calculation, FluidCASIO will overwrite the variable "Γ".

Now, press <EXE> in order to return to the main menu or press <ESC> to finish the FluidCASIO program.

3.3 Uninstalling FluidCASIO

Do as follows:

1. Return to the main menu by pressing the <MENU> key. In the main menu, choose "PRGM" with the help of the cursor block and confirm by pressing <EXE>. All Casio programs are displayed:

2. Search the file "WATER-97".
   Now, press <F4> to delete the file and confirm your entry by pressing <F1>.

   Repeat the deleting process for the following files:

BACKTEST	CBACKS1	CBACKS2A	CBACK2B
COEFREG1	COEFREG4	COEFRG2A	COEFRG2B
GAMMA11	GAMMA11A	GAMMA12	GAMMA13
GAMMA1P1	GAMMA1P2	GAMMA1P3	GAMMA1P4
GAMMA1T1	GAMMA1T2	GAMMA1T3	GAMMA21
GAMMA22	GAMMA23	GAMMA24	GAMMA2P1
GAMMA2P2	GAMMA2P3	GAMMA2T1	GAMMA2T2
GAMMA2T3	GAMMA2T4	PS[T]	REG1TPS
REG2ATPS	REG2BTPS	REGERROR	REGION1
REGION2	REGTEST	TS[P] .	

3. Press the <MENU> key in order to return to the main menu.
   Choose "MAT" in the main menu with the help of the cursor block and confirm by pressing the <EXE> button. Now, search the "Mat Z" matrix.

   Press <F1> to delete the matrix and confirm with the <F1> key.

4. Press the <MENU> key to return to the main menu.

After you have carried out all these steps, FluidCASIO has been removed completely.

4. Program Documentation

Saturation Pressure $p_S = f(t)$

Name in FluidCASIO: ps(t)

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

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 FluidCASIO: ts(p)

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 FluidCASIO: v(p,t,x)

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 that 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: the parameters entered lie beyond 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 FluidCASIO: h(p,t,x)

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* that 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: the parameters entered are located beyond the above mentioned range of validity
(x = -1)

Wet steam region: at p = -1 and t > 350° C or t < 0° C or
($0 \le x \le 1$) 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 Entropy $s = f(p,t,x)$

Name in FluidCASIO: s(p,t,x)

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 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* that 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: the parameters entered are located beyond the above mentioned range of validity
(x = -1)

Wet steam region: at p = -1 and t > 350° C or t < 0° C or
($0 \le x \le 1$) 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]

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

Name in FluidCASIO: t(p,s)

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), with s < 5.85 kJ/(kg K)
Wet steam region:	at values of p > 16.5292 MPa or p < 0.000611 MPa

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

5. References

[1] IAPWS Secretariat, Dooley, B., EPRI, Palo Alto CA (1997):
Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam IAPWS-IF97.

[2] Wagner, W.; Kruse, A. (1998):
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