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

**FluidCASIO
LibIF97
for the
ALGEBRA FX 1.0 and
FX 2.0 PLUS**

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

FluidCASIO LibIF97 for the ALGEBRA FX 1.0 and FX 2.0 PLUS

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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 ALGEBRA FX 1.0 and FX 2.0 PLUS" CD includes the following files:

Program files:

WATER-97.PG	XBACKH1.PG	XBACKH2A.PG	XBACKH2B.PG
XBACKH2C.PG	XBACKS1.PG	XBACKS2A.PG	XBACKS2B.PG
XBACKS2C.PG	XBCKTEST.PG	XBKTEST2.PG	XCOEFRG1.PG
XCOEFRG4.PG	XCOFRG2A.PG	XCOFRG2B.PG	XETA[VT].PG
XGAMM11.PG	XGAMM11A.PG	XGAMM12.PG	XGAMM13.PG
XGAMM1P1.PG	XGAMM1P2.PG	XGAMM1P3.PG	XGAMM1P4.PG
XGAMM1T1.PG	XGAMM1T2.PG	XGAMM1T3.PG	XGAMM21.PG
XGAMM22.PG	XGAMM23.PG	XGAMM24.PG	XGAMM2P1.PG
XGAMM2P2.PG	XGAMM2P3.PG	XGAMM2T1.PG	XGAMM2T2.PG
XGAMM2T3.PG	XGAMM2T4.PG	XLAM[VT].PG	XPS[T].PG
XREGION1.PG	XREGION2.PG	XREGTEST.PG	XRG1TPH.PG
XRG1TPS.PG	XRG2ATPH.PG	XRG2ATPS.PG	XRG2BTPH.PG
XRG2BTPS.PG	XRG2CTPH.PG	XRG2CTPS.PG	XRGERROR.PG
XTS[P].PG	XWETPHS.PG		

User's Guide:

FluidCASIO_ALGEBRA_FX1_FX_2_Water_Docu.pdf

User's Guide will be provided as printed copy in case of shipment

1. Property Functions

Functional Dependence	Function Name in FluidCASIO	Property or Function	Unit
$p_s = f(t)$	ps(t)	Saturation pressure	MPa
$t_s = f(p)$	ts(p)	Saturation temperature	°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)
$t = f(p, h)$	t(p, h)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p, s)$	t(p, s)	Backward function: Temperature from pressure and entropy	°C
$x = f(p, h)$	x(p, h)	Backward function: Vapor fraction from pressure and enthalpy	kg/kg
$x = f(p, s)$	x(p, s)	Backward function: Vapor fraction from pressure and entropy	kg/kg
$c_p = f(p, t, x)$	cp(p, t, x)	Specific isobaric heat capacity	kJ/(kg·K)
$\lambda = f(p, t, x)$	lam(p, t, x)	Thermal conductivity	W/(m·K)
$\eta = f(p, t, x)$	$\eta(p, t, x)$	Dynamic viscosity	Pa·s = kg/(m·s)

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: $p = p_s(t) \dots 100 \text{ MPa}$ at $0 \text{ °C} \dots 350 \text{ °C}$

Steam region 2: $0.000611 \text{ MPa} \dots p = p_s(t)$ at $0 \text{ °C} \dots 350 \text{ °C}$

$0.000611 \text{ MPa} \dots p_{23}(t) = p(s=5.2 \text{ kJ/(kg K)})$ at $350 \text{ °C} \dots 590 \text{ °C}$

$0.000611 \text{ MPa} \dots 100 \text{ MPa}$ at $590 \text{ °C} \dots 800 \text{ °C}$

Details on the vapor fraction x and on the calculation of wet 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. Pressure p and temperature t are given.
- When calculating wet steam, a value between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) must be entered for x .

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 $t = -1$, plus the value for x between 0 and 1.

If values for p and t and x are entered when calculating wet steam, the program will consider p and t to be appropriate to represent the vapor-pressure curve. If this is not the case the calculation for the quantity of the chosen function to be calculated results in -1.

(Range of validity for wet steam: $t = 0 \text{ °C} \dots 350 \text{ °C}$

$p = 0.000611 \text{ MPa} \dots p_s(t=350 \text{ °C}) = 16.5292 \text{ MPa}$)

Note:

If the calculation results in -1 , the values entered represent a state point beyond the range of validity of IAPWS-IF97.

For further information on each function and its range of validity see Chapters 2 and 4.

2. Range of Validity and Program Library Structure

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",

abbreviated and herein after referred to as IAPWS-IF97, in September 1997 [1], [2], [3]. This new industrial standard finds worldwide application in acceptance and guarantee calculations of facilities and plants that work with water or steam. The IAPWS-IF97 Formulation replaces the former Industrial Formulation IFC-67 [12].

Figure 1 shows the entire range of validity of the IAPWS-IF97 equation set. It covers 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.

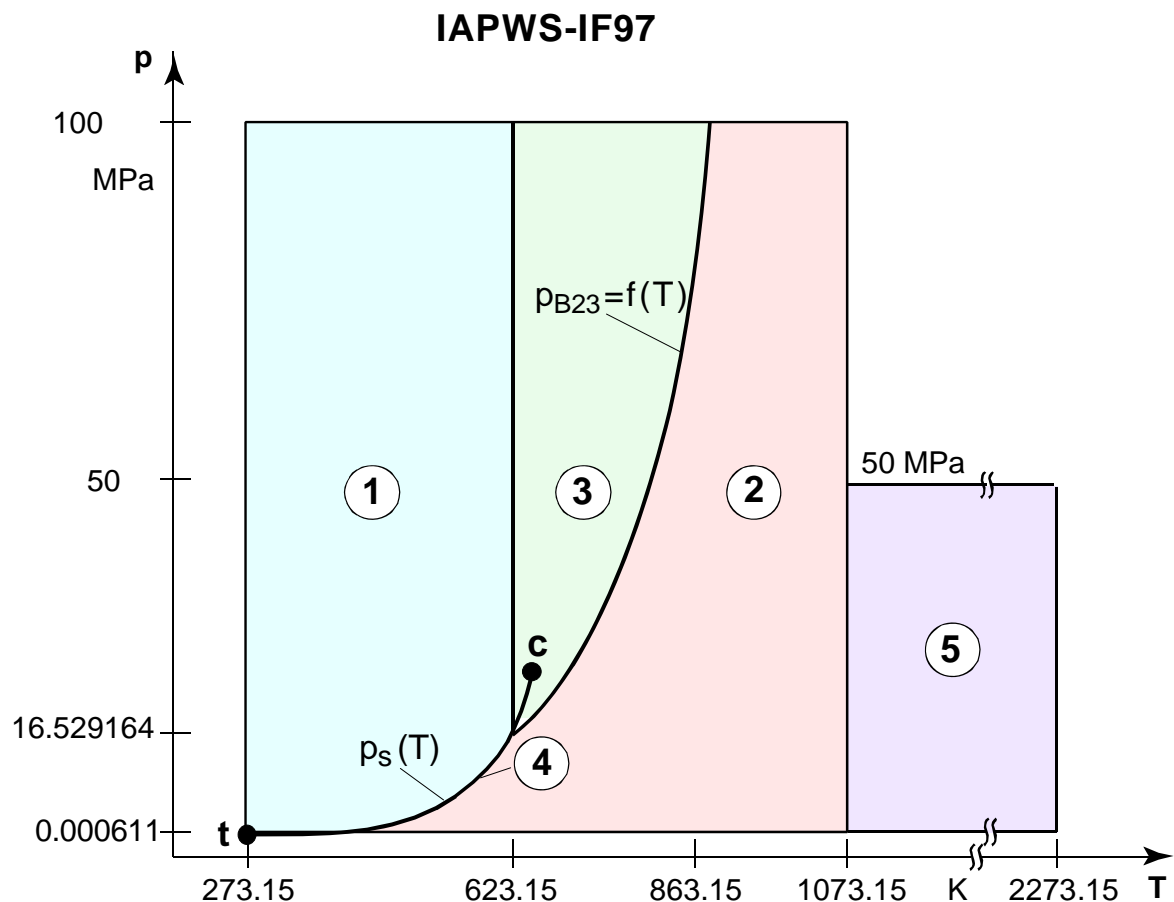


Figure 1: Entire IAPWS-IF97 range of validity

The entire range of validity is divided into five calculation regions. Each region has its own equations of state. For further details see the official IAPWS Release [1] and the publications by *Wagner et al.* [2] and [3].

The FluidCASIO version at hand is valid for the calculation regions 1, 2, and the wet steam region up to a pressure of 16.529164 MPa (cf. Figure 1). The program automatically calls the appropriate equations for each region.

3. Application of FluidCASIO

3.1 Installing FluidCASIO



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

The link program and the link cord are part of the pocket calculator set.

The following description is valid for the

FX-Link-Kit Connection Software®

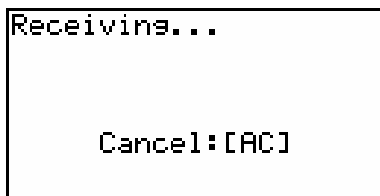
link program which should be installed first. (If different link programs are used for the data transfer, please see the corresponding online helps or user's guides.)


1. Insert the CD "FluidCASIO for the ALGEBRA FX 2.0 PLUS" into the drive of your PC.
2. Start the FX-Link-Kit program on your PC.
3. Click the CD drive in the Directory Tree window (upper left window) .
The CD files are displayed in the upper right-hand window.
4. Click the " " button (Select All) in the receiving window (upper right-hand window).
Now, all files are blue-marked.
5. In this window, click the " " button.
All files selected are copied into the sending window (window below). After the copy process has finished, the file names appear within the sending window below.
6. Connect the Casio calculator to your PC. Plug the link cord in a free PC serial interface (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 "LINK" menu option in the lower menu bar with the help of the cursor block. Confirm by pressing the <EXE> key.

Now, press the <F2> key.

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



8. In the sending window of the FX-Link-Kit, click the " ALL" button to check-mark all files.

Then, click the "" button in the main toolbar of the FX-Link-Kit program.
A dialogue window is displayed.

Click "Start" in order to start the transfer. This takes approximately five minutes. The transfer is complete as soon as the following window is displayed on the Casio calculator:



Press the <ESC> key on the pocket calculator.

Now, the FluidCASIO program is ready for use on your pocket calculator and you can return to the main menu by pressing the <MENU> key.

Note:

If the files have not been copied into the calculator this is due to one of the following errors:

- An inappropriate serial interface and/or the wrong pocket calculator have been preset in the PC link program.

In order to examine this, click "Program" and "Options" in the menu bar. Click the "Connection/Calculator" index card in the following menu.

Select the used interface by clicking the according radio button.

Choose the "FX 1.0" or "Algebra FX 2.0" in the "Calculator" pull-down menu.

Confirm this by clicking "OK".

- The pocket calculator has not been connected when the FX-Link-Kit[®] was started.
- The plugs have not been put in correctly.
- An inappropriate or defective link cord has been used.

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

We will now calculate, step by step, the specific enthalpy h is as a function of pressure p , temperature t and vapor fraction x corresponding to the IAPWS-IF97 Industrial Formulation [1, 2, 3] using FluidCASIO.

Proceed as follows:

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

By using the cursor block, choose the "WATER-97" program file and confirm your selection by pressing the <EXE> key.

- The following FluidCASIO main menu with its property functions is displayed:

```
Water - IF97
<1>  → Ps(t)
<2>  → ts(P)
<3>  → v(P,t,x)
<4>  → h(P,t,x)
<5>  → s(P,t,x)
<EXE> → continue
```

Press <EXE> for further functions:

```
Water - IF97
<6>  → t(P,h)
<7>  → t(P,s)
<8>  → x(P,h)
<9>  → x(P,s)
<0>  → cp(P,t,x)
<EXE> → continue
```

Press <EXE> again to see further functions and menu options:

```
Water - IF97
<x>  → lam(P,t,x)
</>  → n(P,t,x)
<+>  → help
<->  → about
<EXE> → menu begin
<ESC> → exit
```

Press the <EXE>key again to return to the first part of the menu.

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

```
P in MPa?
0.1
-2 → take this value
```

Consider the IAPWS-IF97 range of validity.

Liquid region: $p = p_s(t) \dots 100 \text{ MPa}$ for $0 \text{ }^\circ\text{C} \dots 350 \text{ }^\circ\text{C}$ (region 1 in figure 1)

Vapor region: $0.000611 \text{ MPa} \dots p = p_s(t)$ for $0 \text{ }^\circ\text{C} \dots 350 \text{ }^\circ\text{C}$ (region 2 in figure 1)
 $0.000611 \text{ MPa} \dots p_{23}(t) \approx p(s=5.2 \text{ kJ/kgK})$ for $350 \text{ }^\circ\text{C} \dots 590 \text{ }^\circ\text{C}$
 $0.000611 \text{ MPa} \dots 100 \text{ MPa}$ for $590 \text{ }^\circ\text{C} \dots 800 \text{ }^\circ\text{C}$.

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

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

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

```
t in °C?
100
-2 ⇒ take this value
```

Consider the IAPWS-IF97 range of validity.

Liquid region: $t=0\text{ °C} \dots 350\text{ °C}$ for $p=p_s(t) \dots 100\text{ MPa}$ (region 1 in figure 1)

Vapor region: $0\text{ °C} \dots 350\text{ °C}$ for $0.000611\text{ MPa} \dots p=p_s(t)$ (region 2 in figure 1)

$350\text{ °C} \dots 590\text{ °C}$ for $0.000611\text{ MPa} \dots p_{23}(t) \approx p(s=5.2\text{ kJ/kgK})$

$590\text{ °C} \dots 800\text{ °C}$ for $0.000611\text{ MPa} \dots 100\text{ MPa}$.

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

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

```
x in kg/kg?
-1
-2 ⇒ take this value
```

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. Pressure p and temperature t are given.
- When calculating wet steam, a value between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) must be entered for x .

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 $t = -1$, plus the value for x between 0 and 1.

If values for p and t and x are entered when calculating wet steam, the program will consider p and t to be appropriate to represent the vapor-pressure curve. If this is not the case the calculation for the quantity of the chosen function to be calculated results in -1.

Wet steam region: $t = 0\text{ °C} \dots 350\text{ °C}$

$p = 0.000611\text{ MPa} \dots p_s(t=350\text{ °C}) = 16.5292\text{ MPa}$

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

- During the calculation, the following window is displayed:

```
FluidCasio is working
```

- After the calculation, the result for h in kJ/kg is displayed:

```
Steam region
h_in kJ/kg
3097.375274

<EXE> ↗ main menu
<ESC> ↗ exit
```

→ In the example, the function 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).

Further on, this variable can be used independently of FluidCASIO.

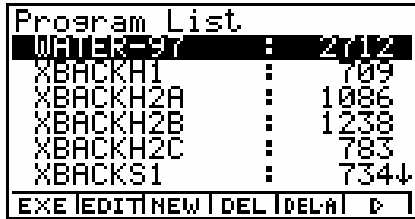
With the next calculation, FluidCASIO overwrites the variable "Γ" .

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

3.3 Removing FluidCASIO

Proceed as follows:

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



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



Repeat the deleting procedure for the following files:

XBACKH1.PG	XBACKH2A.PG	XBACKH2B.PG	XBACKH2C.PG
XBACKS1.PG	XBACKS2A.PG	XBACKS2B.PG	XBACKS2C.PG
XBCKTEST.PG	XBKTEST2.PG	XCOEFRG1.PG	XCOEFRG4.PG
XCOFRG2A.PG	XCOFRG2B.PG	XETA[VT].PG	XGAMM11.PG
XGAMM11A.PG	XGAMM12.PG	XGAMM13.PG	XGAMM1P1.PG
XGAMM1P2.PG	XGAMM1P3.PG	XGAMM1P4.PG	XGAMM1T1.PG
XGAMM1T2.PG	XGAMM1T3.PG	XGAMM21.PG	XGAMM22.PG
XGAMM23.PG	XGAMM24.PG	XGAMM2P1.PG	XGAMM2P2.PG
XGAMM2P3.PG	XGAMM2T1.PG	XGAMM2T2.PG	XGAMM2T3.PG
XGAMM2T4.PG	XLAM[VT].PG	XPS[T].PG	XREGION1.PG
XREGION2.PG	XREGTEST.PG	XRG1TPH.PG	XRG1TPS.PG
XRG2ATPH.PG	XRG2ATPS.PG	XRG2BTPH.PG	XRG2BTPS.PG
XRG2CTPH.PG	XRG2CTPS.PG	XRGERROR.PG	XTS[P].PG
XWETPHS.PG			

3. Press the <MENU> key in order to return to the main menu.

After you have carried out 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 $t_t = 0$ °C up to $t_c = 373.946$ °C

Response on faulty input values

The error message "Out of Range!" is displayed 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

The error message "Out of Range!" is displayed 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 m³/kg

Range of validity

Liquid region: $p = p_s(t) \dots 100 \text{ MPa}$ at $0 \text{ °C} \dots 350 \text{ °C}$

Steam region: $0.000611 \text{ MPa} \dots p = p_s(t)$ at $0 \text{ °C} \dots 350 \text{ °C}$

$0.000611 \text{ MPa} \dots p_{23}(t) = p(s=5.2 \text{ kJ}/(\text{kg K}))$ at $350 \text{ °C} \dots 590 \text{ °C}$

$0.000611 \text{ MPa} \dots 100 \text{ MPa}$ at $590 \text{ °C} \dots 800 \text{ °C}$

Details on the vapor fraction x and on the calculation of wet 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. Pressure p and temperature t are given.
- When calculating wet steam, x results in a value between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam).

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 $t = -1$, plus the value for x between 0 and 1.

If values for p and t and x are entered when calculating wet steam, the program will consider p and t to be appropriate to represent the vapor-pressure curve. If this is not the case the calculation for the quantity of the chosen function to be calculated results in -1.

Wet steam region: $t = 0 \text{ °C} \dots 350 \text{ °C}$

$p = 0.000611 \text{ MPa} \dots 16.5292 \text{ MPa}$

Response on faulty input values

The error message "Out of Range!" is displayed 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:

($0 \leq x \leq 1$) at $t = -1$ and $p > 16.5292 \text{ MPa}$ or $p < 0.000611 \text{ MPa}$ or
 at $p > 16.5292 \text{ MPa}$ or $p < 0.000611 \text{ MPa}$
 and $t > 350 \text{ °C}$ or $t < 0 \text{ °C}$
 at $|t - t_s(p)| > 0.1 \text{ K}$

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

Details on the vapor fraction x and on the calculation of wet 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. Pressure p and temperature t are given.
- When calculating wet steam, x results in a value between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam).

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 $t = -1$, plus the value for x between 0 and 1.

If values for p and t and x are entered when calculating wet steam, the program will consider p and t to be appropriate to represent the vapor-pressure curve. If this is not the case the calculation for the quantity of the chosen function to be calculated results in -1.

Wet steam region: $t = 0 \text{ °C} \dots 350 \text{ °C}$
 $p = 0.000611 \text{ MPa} \dots 16.5292 \text{ MPa}$

Response on faulty input values

The error message "Out of Range!" is displayed 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 $t > 350 \text{ °C}$ or $t < 0 \text{ °C}$ or
 ($0 \leq x \leq 1$) at $t = -1$ and $p > 16.5292 \text{ MPa}$ or $p < 0.000611 \text{ MPa}$ or
 at $p > 16.5292 \text{ MPa}$ or $p < 0.000611 \text{ MPa}$
 and $t > 350 \text{ °C}$ or $t < 0 \text{ °C}$
 at $|t - t_s(p)| > 0.1 \text{ K}$

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: $p = p_s(t) \dots 100 \text{ MPa}$ at $0 \text{ °C} \dots 350 \text{ °C}$

Steam region: $0.000611 \text{ MPa} \dots p = p_s(t)$ at $0 \text{ °C} \dots 350 \text{ °C}$

$0.000611 \text{ MPa} \dots p_{23}(t) = p(s=5.2 \text{ kJ/(kg K)})$ at $350 \text{ °C} \dots 590 \text{ °C}$

$0.000611 \text{ MPa} \dots 100 \text{ MPa}$ at $590 \text{ °C} \dots 800 \text{ °C}$

Details on the vapor fraction x and on the calculation of wet 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. Pressure p and temperature t are given.
- When calculating wet steam, x results in a value between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam).

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 $t = -1$, plus the value for x between 0 and 1.

If values for p and t and x are entered when calculating wet steam, the program will consider p and t to be appropriate to represent the vapor-pressure curve. If this is not the case the calculation for the quantity of the chosen function to be calculated results in -1.

Wet steam region: $t = 0 \text{ °C} \dots 350 \text{ °C}$

$p = 0.000611 \text{ MPa} \dots 16.5292 \text{ MPa}$

Response on faulty input values

The error message "Out of Range!" is displayed for the following input values:

Single-phase region: the parameters entered lie beyond the above mentioned range of validity ($x = -1$)

Wet steam region: at $p = -1$ and $t > 350 \text{ °C}$ or $t < 0 \text{ °C}$ or

($0 \leq x \leq 1$) at $t = -1$ and $p > 16.5292 \text{ MPa}$ or $p < 0.000611 \text{ MPa}$ or

at $p > 16.5292 \text{ MPa}$ or $p < 0.000611 \text{ MPa}$

and $t > 350 \text{ °C}$ or $t < 0 \text{ °C}$

at $| t - t_s(p) | > 0.1 \text{ K}$

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

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

Name in FluidCASIO: $t(p,h)$

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: $p = 0.000611 \dots 16.5292$ MPa and $h'(p) < h < h''(p)$

Comment on the calculations for wet steam

The wet steam region is calculated automatically by the subprograms. With reference to the given values of p and h , a subroutine calculation decides whether the state point to be calculated is located in the single-phase region (liquid or steam), or in the wet steam region. The appropriate region of state is then calculated.

Response on faulty input values

The error message "Out of Range!" is displayed 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 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: $p = 0.000611 \dots 16.5292$ MPa

Comment on the calculations for wet steam

The wet steam region is calculated automatically by the subprograms. With reference to the given values of p and h , a subroutine calculation decides whether the state point to be calculated is located in the single-phase region (liquid or steam), or in the wet steam region. The appropriate region of state is then calculated.

Response on faulty input values

The error message "Out of Range!" is displayed 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)

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 FluidCASIO: $x(p,h)$

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: $p = 0.000611 \dots 16.5292$ MPa and $h'(p) < h < h''(p)$

Comment on the calculations for wet steam

The wet steam region is calculated automatically by the subprograms. With reference to the given values of p and h , a subroutine calculation decides whether the state point to be calculated is located in the single-phase region (liquid or steam), or in the wet steam region.

If the state point to be calculated is located in the wet steam region the value of x is calculated. If the state point to be calculated is located in the single-phase region the calculation results in -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:

$$p > 16.5292 \text{ MPa or } h < h'(p) \text{ or } h > h''(p)$$

The error message "Out of Range!" is displayed for the following input values:

$$p < 0.000611 \text{ MPa or } p > 100 \text{ MPa}$$

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

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

Name in FluidCASIO: $x(p,h)$

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: $p = 0.000611 \dots 16.5292$ MPa and $s'(p) < s < s''(p)$

Comment on the calculations for wet steam

The wet steam region is calculated automatically by the subprograms. With reference to the given values of p and h , a subroutine calculation decides whether the state point to be calculated is located in the single-phase region (liquid or steam), or in the wet steam region.

If the state point to be calculated is located in the wet steam region the value of x is calculated. If the state point to be calculated is located in the single-phase region the calculation results in -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:

$$p > 16.5292 \text{ MPa or } h < h'(p) \text{ or } h > h''(p)$$

The error message "Out of Range!" is displayed for the following input values:

$$p < 0.000611 \text{ MPa or } p > 100 \text{ MPa}$$

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

Dynamic Viscosity $\eta = f(p, t, x)$

Name in FluidCASIO: $\eta(p, t, x)$

Input

p - Pressure p in MPa

t - Temperature t in °C

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

Output

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

Range of validity

Liquid region: $p = p_s(t) \dots 100 \text{ MPa}$ at $0 \text{ °C} \dots 350 \text{ °C}$

Steam region: $0.000611 \text{ MPa} \dots p = p_s(t)$ at $0 \text{ °C} \dots 350 \text{ °C}$

$0.000611 \text{ MPa} \dots p_{23}(t) = p(s=5.2 \text{ kJ/(kg K)})$ at $350 \text{ °C} \dots 590 \text{ °C}$

$0.000611 \text{ MPa} \dots 100 \text{ MPa}$ at $590 \text{ °C} \dots 800 \text{ °C}$

Details on the vapor fraction x and on the calculation of wet 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. Pressure p and temperature t are given.

If the state point to be calculated is saturated liquid the value $x = 0$ has to be entered. When calculating saturated steam the value 1 has to be entered for x . A calculation of values between 0 and 1 is not possible.

When calculating saturated liquid and saturated 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 ($x = 0$ or $x = 1$). If p and t and x are entered, the program considers p and t to represent the vapor-pressure curve. If this is not the case the calculation for the quantity of the chosen function to be calculated results in -1.

Saturated liquid and saturated vapor: $t = 0 \text{ °C} \dots 350 \text{ °C}$

$p = 0.000611 \text{ MPa} \dots 16.5292 \text{ MPa}$

Response on faulty input values

The error message "Out of Range!" is displayed for the following input values:

Single-phase region: the parameters entered lie beyond the above mentioned range of validity ($x = -1$)

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

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

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

Name in FluidCASIO: lam(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

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

Range of validity

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

Details on the vapor fraction x and on the calculation of wet 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. Pressure p and temperature t are given.

If the state point to be calculated is saturated liquid the value $x = 0$ has to be entered. When calculating saturated steam the value 1 has to be entered for x . A calculation of values between 0 and 1 is not possible.

When calculating saturated liquid and saturated 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 ($x = 0$ or $x = 1$). If p and t and x are entered, the program considers p and t to represent the vapor-pressure curve. If this is not the case the calculation for the quantity of the chosen function to be calculated results in -1.

Saturated liquid and saturated vapor: $t = 0 \text{ °C} \dots 350 \text{ °C}$
 $p = 0.000611 \text{ MPa} \dots 16.5292 \text{ MPa}$

Response on faulty input values

The error message "Out of Range!" is displayed for the following input values:

Single-phase region: the parameters entered lie beyond the above mentioned range of validity ($x = -1$)

Saturated liquid and saturated vapor: $(x = 0 \text{ or } x = 1)$

- at $p = -1$ and $t > 350 \text{ °C}$ or $t < 0 \text{ °C}$ or
- at $t = -1$ and $p > 16.5292 \text{ MPa}$ or $p < 0.000611 \text{ MPa}$ or
- at $p > 16.5292 \text{ MPa}$ or $p < 0.000611 \text{ MPa}$
- and $t > 350 \text{ °C}$ or $t < 0 \text{ °C}$
- at $|t - t_s(p)| > 0.1 \text{ K}$

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 FluidCASIO: cp(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

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

Range of validity

Liquid region: $p = p_s(t) \dots 100 \text{ MPa}$ at $0 \text{ °C} \dots 350 \text{ °C}$

Steam region: $0.000611 \text{ MPa} \dots p = p_s(t)$ at $0 \text{ °C} \dots 350 \text{ °C}$

$0.000611 \text{ MPa} \dots p_{23}(t) = p(s=5.2 \text{ kJ/(kg K)})$ at $350 \text{ °C} \dots 590 \text{ °C}$

$0.000611 \text{ MPa} \dots 100 \text{ MPa}$ at $590 \text{ °C} \dots 800 \text{ °C}$

Details on the vapor fraction x and on the calculation of wet 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. Pressure p and temperature t are given.

If the state point to be calculated is saturated liquid the value $x = 0$ has to be entered. When calculating saturated steam the value 1 has to be entered for x . A calculation of values between 0 and 1 is not possible.

When calculating saturated liquid and saturated 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 ($x = 0$ or $x = 1$). If p and t and x are entered, the program considers p and t to represent the vapor-pressure curve. If this is not the case the calculation for the quantity of the chosen function to be calculated results in -1.

Saturated liquid and saturated vapor: $t = 0 \text{ °C} \dots 350 \text{ °C}$

$p = 0.000611 \text{ MPa} \dots 16.5292 \text{ MPa}$

Response on faulty input values

The error message "Out of Range!" is displayed for the following input values:

Single-phase region: the parameters entered lie beyond the above mentioned range of validity ($x = -1$)

Saturated liquid and saturated vapor: ($x = 0$ or $x = 1$)

- at $p = -1$ and $t > 350 \text{ °C}$ or $t < 0 \text{ °C}$ or
- at $t = -1$ and $p > 16.5292 \text{ MPa}$ or $p < 0.000611 \text{ MPa}$ or
- at $p > 16.5292 \text{ MPa}$ or $p < 0.000611 \text{ MPa}$
- and $t > 350 \text{ °C}$ or $t < 0 \text{ °C}$
- at $|t - t_s(p)| > 0.1 \text{ K}$

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

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