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

**FluidCASIO**

**LibIF97**

**for the**

**ALGEBRA 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 2.0 PLUS

### Contents

0. Package Contents
1. IAPWS-IF97 Functions
2. Range of Validity and Program Library Structure
3. Application of FluidCASIO
  - 3.1 Installing FluidCASIO
  - 3.2 Example: Calculate  $h = f(p, t, x)$
  - 3.3 Uninstall FluidCASIO
4. Program Documentation
5. References

For further pocket calculator software see the following link:

[www.steamtables-pocket-calculators.com](http://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](http://www.international-steam-tables.com)

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## 0. Package Contents

The "FluidCASIO for the ALGEBRA FX 2.0 PLUS" CD includes the following 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		

FluidCASIO\_ALGEBRA\_FX\_2\_Docu.pdf - software documentation

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

## 1. IAPWS-IF97 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 <sup>3</sup> /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)
$\eta = f(p,t,x)$	η(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  $590 \text{ °C} \dots 800 \text{ °C}$

### Comment on the vapor fraction $x$ and calculations for wet steam

Since the wet steam region is calculated automatically, the following details on the vapor fraction  $x$  are to be regarded:

- Should the point of state to be calculated lie in the single-phase regions (of liquid or superheated vapor) enter -1 as the value for  $x$ . Pressure  $p$  and temperature  $t$  are given.
- Should the point of state to be calculated lie in the wet steam region the value to be entered for  $x$  ranges between 0 and 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  $x$  between 0 and 1.

Should  $p$  and  $t$  and  $x$  be entered for the calculation of wet steam the program considers  $p$  and  $t$  to represent the vapor-pressure curve. Should this not be the case the calculation results in -1.

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

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

#### **Please note.**

Should the input values lie beyond the IAPWS-IF97 range of validity or do not define a point of state the function calculated always results in -1.

For further information on the IAPWS-IF97 range of validity see chapters 2 and 4.

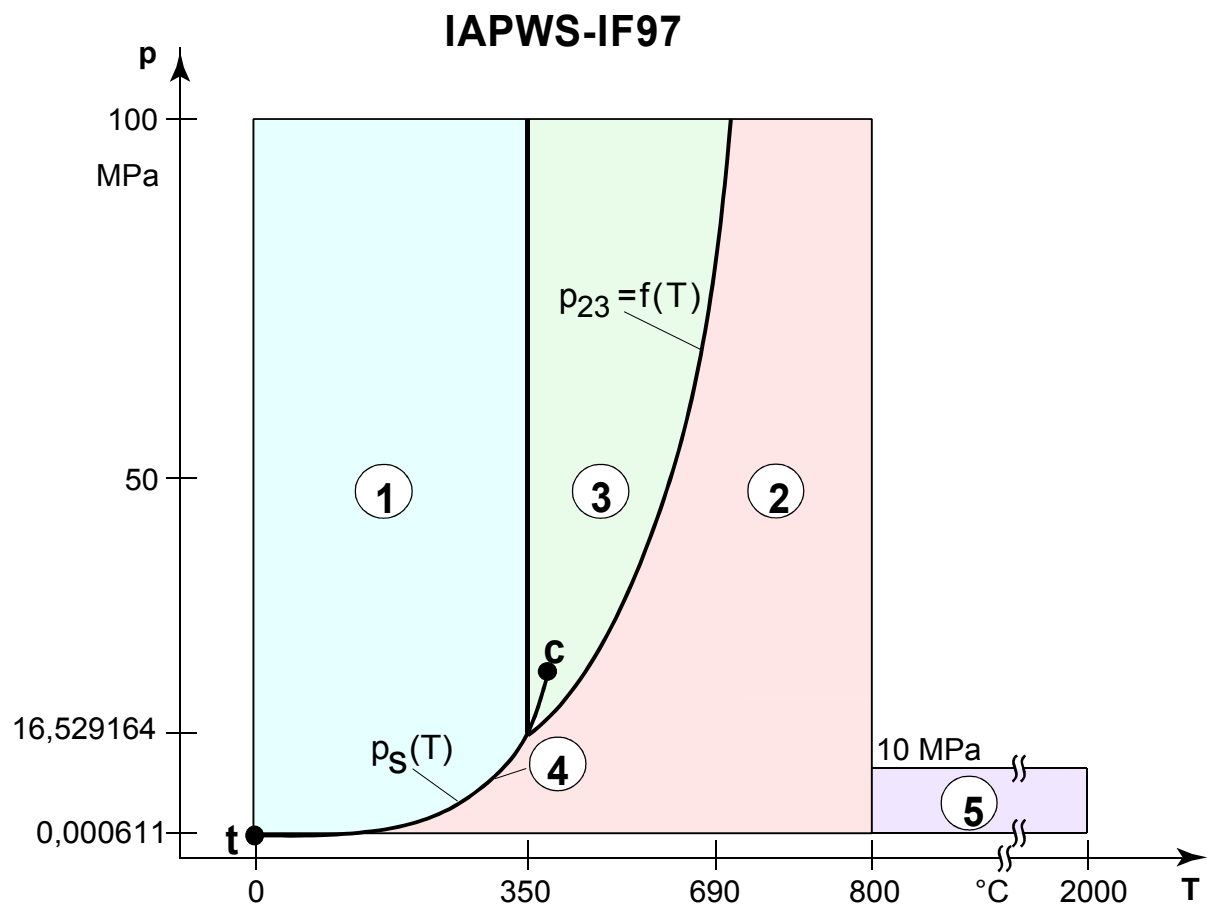
## 2. Range of Validity and Program Library Structure

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 10 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. Figure1). For each region, the program automatically calls the appropriate equations.

## 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 cable.

The link program and the link cable 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. (Should different link programs be used for the data transfer see the corresponding online helps or user's guides.)

1. Insert the "FluidCASIO for the ALGEBRA FX 2.0 PLUS" CD into the drive of the PC.
2. Start the FX-Link-Kit program on the PC.
3. Click in the Directory Tree window (upper left window) on the CD drive.  
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 should be blue-marked.
5. In this window, click the button "⊕" .  
All files selected are copied into the sending window (lower window).
6. Connect the Casio calculator with the PC. Plug the link cable 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 with the <EXE> key.


Now, press the <F2> key.


The Casio computer waits for receiving data. The following screen is displayed:

```

Receivins...

                Cancel:[AC]
  
```

8. In the sending window of the FX-Link-Kit, click the  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. It approximately takes 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 pressing the <MENU> key.

**Note:**

Should the files not have 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 clicking the according radio button.

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

Confirm this clicking "OK".

- The pocket calculator has not been connected when the FX-Link-Kit<sup>®</sup> was started.
- The plugs have not been put in correctly.
- An inappropriate or defective link cable has been used.

### 3.2 Example: Calculate $h = f(p, t, x)$

For the IAPWS-IF97 Industrial Formulation [1, 2, 3], the specific enthalpy  $h$  is to be calculated as a function of pressure  $p$ , temperature  $t$  and vapor fraction  $x$ .

Do as follows:

- Press the <MENU> key 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 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
```

Again, press <EXE> for further functions and menu options:

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

Press again <EXE> 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.

$p = 0.000611 \dots 100$  MPa.

→ E.g.: Enter the value 10 and confirm with <EXE>.

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

$$t = 0 \text{ °C} \dots 800 \text{ °C}$$

→ E.g.: Enter the value 400 and confirm with <EXE>.

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
```

Since the wet steam region is calculated automatically, the following details on the vapor fraction  $x$  are to be regarded:

- Should the point of state to be calculated lie in the single-phase regions (of liquid or superheated vapor) enter -1 as the value for  $x$ . Pressure  $p$  and temperature  $t$  are given.
- Should the point of state to be calculated lie in the wet steam region the value to be entered for  $x$  ranges between 0 and 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  $x$  between 0 and 1.

Should  $p$  and  $t$  and  $x$  be entered for the calculation of wet steam the program considers  $p$  and  $t$  to represent the vapor-pressure curve. Should this not be the case the calculation results in -1.

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

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

→ The point to be calculated lies 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 "I" (gamma).

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

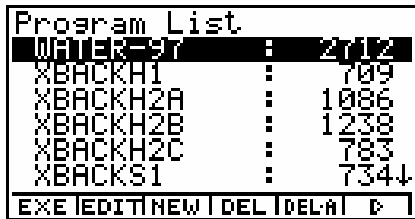
With the next calculation, FluidCASIO overwrites the variable "Γ" .

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

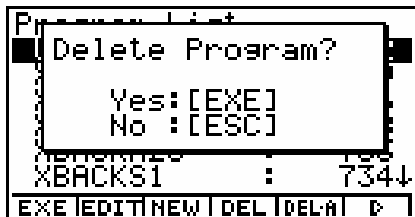
### 3.3 Uninstall FluidCASIO

Do as follows:

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



2. Search the "WATER-97" file.  
Now, press <F4> to delete the file and confirm with <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
XBKTEST.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.

With all steps executed, FluidCASIO has been uninstalled.

## 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]

<b>Specific Volume <math>v = f(p,t,x)</math></b>
--------------------------------------------------

**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<sup>3</sup>/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  $590 \text{ °C} \dots 800 \text{ °C}$

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

Since the wet steam region is calculated automatically, the following details on the vapor fraction x are to be regarded:

- Should the point of state to be calculated lie in the single-phase regions (of liquid or superheated vapor) enter -1 as the value for x. Pressure p and temperature t are given.
- Should the point of state to be calculated lie in the wet steam region the value to be entered for x ranges between 0 and 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 between 0 and 1.

Should p and t and x be entered for the calculation of wet steam the program considers p and t to represent the vapor-pressure curve. Should this not be the case the calculation 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:

$(0 \leq x \leq 1)$  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  $0 \text{ °C} \dots 350 \text{ °C}$

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

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

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

Since the wet steam region is calculated automatically, the following details on the vapor fraction x are to be regarded:

- Should the point of state to be calculated lie in the single-phase regions (of liquid or superheated vapor) enter -1 as the value for x. Pressure p and temperature t are given.
- Should the point of state to be calculated lie in the wet steam region the value to be entered for x ranges between 0 and 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 between 0 and 1.

Should p and t and x be entered for the calculation of wet steam the program considers p and t to represent the vapor-pressure curve. Should this not be the case the calculation 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:  $(0 \leq x \leq 1)$

- 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]

## 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  $590 \text{ °C} \dots 800 \text{ °C}$

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

Since the wet steam region is calculated automatically, the following details on the vapor fraction x are to be regarded:

- Should the point of state to be calculated lie in the single-phase regions (of liquid or superheated vapor) enter -1 as the value for x. Pressure p and temperature t are given.
- Should the point of state to be calculated lie in the wet steam region the value to be entered for x ranges between 0 and 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 between 0 and 1.

Should p and t and x be entered for the calculation of wet steam the program considers p and t to represent the vapor-pressure curve. Should this not be the case the calculation 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]

<b>Backward Function: Temperature <math>t = f(p,h)</math></b>
---------------------------------------------------------------

**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. With reference to the given values of p and h, a subroutine calculation decides whether the point of state to be calculated lies 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]

<b>Backward Function: Temperature <math>t = f(p,s)</math></b>
---------------------------------------------------------------

**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. With reference to the given values of p and h, a subroutine calculation decides whether the point of state to be calculated lies 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]

<b>Backward Function: Vapor Fraction <math>x = f(p,h)</math></b>
------------------------------------------------------------------

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

Should the point of state to be calculated lie in the wet steam region the value of x is calculated. Should the point of state to be calculated lie in the single-phase region the calculation results in -1.

**Response on faulty input values**

Should the point of state to be calculated lie 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. With reference to the given values of p and h, a subroutine calculation decides whether the point of state to be calculated lies in the single-phase region (liquid or steam), or in the wet steam region.

Should the point of state to be calculated lie in the wet steam region the value of x is calculated. Should the point of state to be calculated lie in the single-phase region the calculation results in -1.

**Response on faulty input values**

Should the point of state to be calculated lie 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]

<b>Dynamic Viscosity <math>\eta = f(p,t,x)</math></b>
-------------------------------------------------------

**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  $\eta$  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  $590 \text{ °C} \dots 800 \text{ °C}$

**Comment on the vapor fraction x and the calculations for saturated liquid and saturated vapor**

Since the wet steam region is calculated automatically the following details on the vapor fraction x are to be regarded:

Should the point of state to be calculated lie in the single-phase regions (of liquid or superheated vapor) enter the value -1 for x. Pressure p and temperature t are given.

Should the point of state to be calculated is saturated liquid the value  $x = 0$  has to be entered. In case of saturated vapor 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 vapor 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. Should this not be the case the calculation 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  $\rho$  or  $v$ : [1], [2], [3], [4], [5]

<b>Thermal Conductivity <math>\lambda = f(p,t,x)</math></b>
-------------------------------------------------------------

**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  $\lambda$  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  $590 \text{ °C} \dots 800 \text{ °C}$

**Comment on the vapor fraction x and the calculations for saturated liquid and saturated vapor**

Since the wet steam region is calculated automatically the following details on the vapor fraction x are to be regarded:

Should the point of state to be calculated lie in the single-phase regions (of liquid or superheated vapor) enter the value -1 for x. Pressure p and temperature t are given.

Should the point of state to be calculated is saturated liquid the value  $x = 0$  has to be entered. In case of saturated vapor 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 vapor 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. Should this not be the case the calculation 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  $\rho$  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  $0 \text{ °C} \dots 350 \text{ °C}$

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

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

### Comment on the vapor fraction x and the calculations for saturated liquid and saturated vapor

Since the wet steam region is calculated automatically the following details on the vapor fraction x are to be regarded:

Should the point of state to be calculated lie in the single-phase regions (of liquid or superheated vapor) enter the value -1 for x. Pressure p and temperature t are given.

Should the point of state to be calculated is saturated liquid the value  $x = 0$  has to be entered. In case of saturated vapor 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 vapor 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. Should this not be the case the calculation 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  
 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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