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

**FluidHP for the
HP 49 Pocket Calculator**

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FluidHP for the HP 49 Pocket Calculator

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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 "FluidHP for the HP 49" CD includes the following files:

\FLHP with the program files

PB1B
PB1H
PB1S
PB2B
PB2H
PB2S
PB4B
PBER
PBUM
PBUX
PETL
PHEL
PINP
PMENU
POUT
PPST
PSHR
PTSP

and the RUN file.

FluidHP49_LibIF97_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 FluidHP	Property or Function	Units
$p_s = f(t)$	$p_s=f(t)$	Saturation pressure from temperature	MPa
$t_s = f(p)$	$t_s=f(p)$	Saturation temperature from pressure	°C
$v = f(p,t,x)$	$v=f(p,t,x)$	Specific volume	m ³ /kg
$h = f(p,t,x)$	$h=f(p,t,x)$	Specific enthalpy	kJ/kg
$s = f(p,t,x)$	$s=f(p,t,x)$	Specific entropy	kJ/(kg·K)
$c_p = f(p,t,x)$	$c_p=f(p,t,x)$	Specific isobaric heat capacity	kJ/(kg·K)
$\lambda = f(p,t,x)$	$\lambda=f(p,t,x)$	Thermal conductivity	W/(m·K)
$\eta = f(p,t,x)$	$\eta=f(p,t,x)$	Dynamic viscosity	Pa · s = kg/(m·s)
$t = f(p,h)$	$t=f(p,h)$	Backward function: temperature from pressure and enthalpy	°C
$x = f(p,h)$	$x=f(p,h)$	Backward function: vapor fraction from pressure and enthalpy	kg/kg
$t = f(p,s)$	$t=f(p,s)$	Backward function: temperature from pressure and entropy	°C
$x = f(p,s)$	$x=f(p,s)$	Backward function: vapor fraction from pressure and entropy	kg/kg

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 (Figure 1)

Region 1: $p = p_s(t) \dots 100 \text{ MPa}$ at $0 \text{ °C} \dots 350 \text{ °C}$

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

2. Range of Validity and Program Library Structure

The International Association for the Properties of Water and Steam IAPWS declared the new IAPWS-IF97 Industrial Formulation for thermodynamic properties of water and steam, referred to as the IF97, internationally binding in September 1997 [1], [2], [3]. That is, this new standard finds worldwide application in final inspection and warranty invoices for plants that use the working fluid water or steam. The IAPWS-IF97 Formulation replaces the former Industrial Formulation IFC-67 [12].

Figure 1 displays the range of validity of the new Industrial Formulation's equation theorem, fully named

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

abbreviated

"IAPWS Industrial Formulation 1997" .

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 10 MPa.

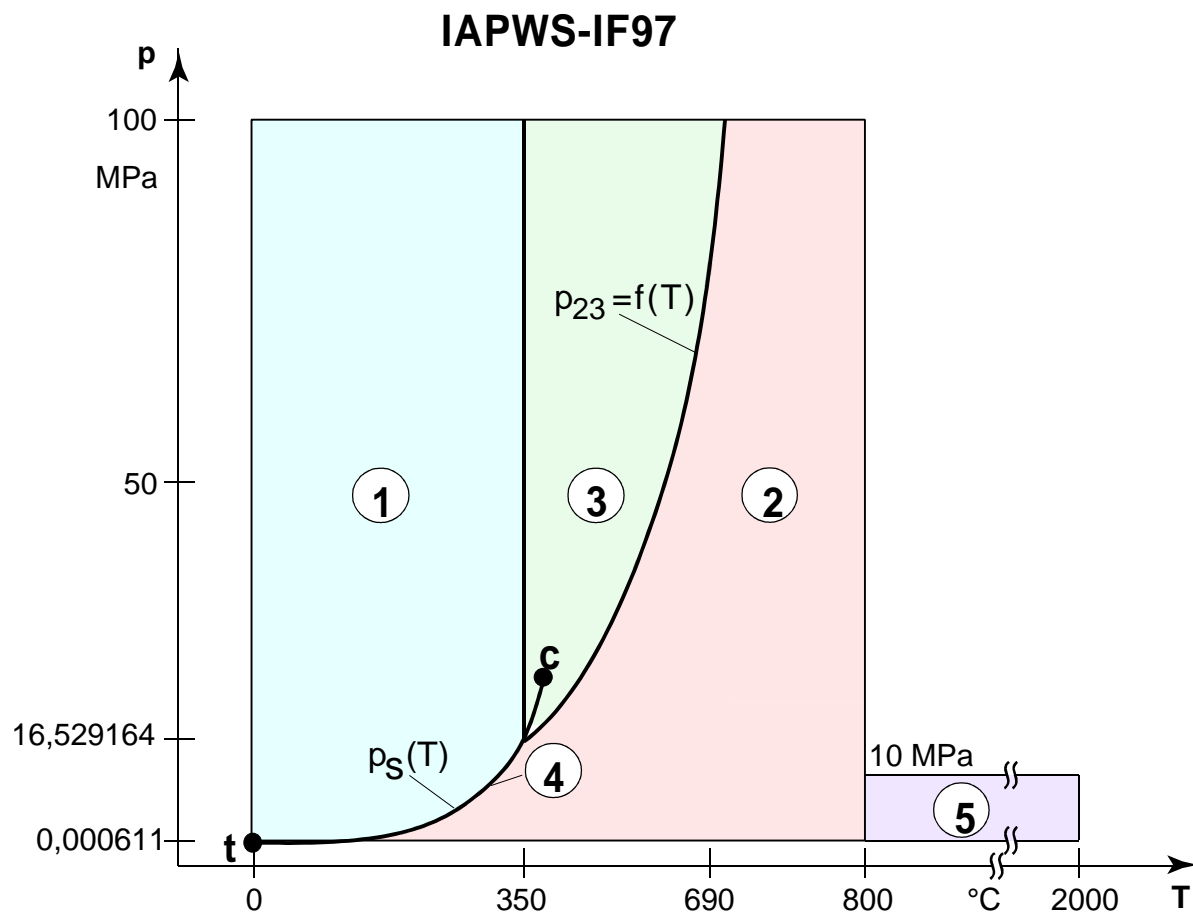


Figure 1: Range of Validity of the IAPWS-IF97

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

The FluidHP 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. Figure 1). Their connection to the calculation equations is established according to the given quantities.

3. Application of FluidHP

3.1 Installing FluidHP

In order to run the FluidHP 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 and the link cable should be attached to the pocket calculator. If they are not request those at Böttcher Datentechnik GmbH (<http://www.boettcher-datentechnik.de/>) or in a specialist shop.

The following description is valid for the

PC Connectivity Kit 3.0®

link program which should have already been installed. (For another link program used for the file transfer see the corresponding user's guide or online-help.)

1. Connect the HP49 with the PC: Plug the link cable in a free serial interface of the PC (COM1 or COM2) and in the pocket calculator. When doing so, switch off both devices.

In order to switch on the pocket calculator and to prepare it for the data transfer, press the <ON> button.

2. In order to check whether there is enough memory capacity available press the following buttons one after another: <↔> , and <FILES>. The FILE MANAGER is displayed on the screen. In the "Home" directory, at least 28 Kbytes memory capacity should be available in order to run FluidHP. If there is less, delete old programs and variables or execute a memory reset. (For further details on this topic see the pocket calculator's user's guide.) Now, leave this menu pressing the <ON> key.
3. Start the server mode pressing the <APPS> key. Then, choose "2. I/O functions.." and confirm with "OK" (<F6> key).

Now, choose "6. Start Server" and confirm with "OK". The message "Awaiting Server Cmd." is displayed on the screen.

4. Switch on the PC and start the *PC Connectivity Kit 3.0*® link program. In some cases, the "Communication settings" menu is displayed:

<u>Option</u>	<u>Setting</u>
COM port	Select the PC serial communication port that the cable is connected to.
Type	Ignore this setting in this PC Connectivity Kit version.
Translation	Set the translation type you wish to use to translate the calculator programs you develop on the PC. The PC Connectivity Kit configures the calculator for the type that you select. The default setting is "Mode 1".
Checksum	Set the checksum type you set on the calculator. The default setting is "Type 1".
Speed	Select the rate you set on the calculator. The default rate is 9600.

5. After a brief confirmation that the calculator has been connected, the "HP Graphing Calculator PC ..." window is displayed on the PC screen. The upper section displays the PC folders and files, the lower section displays the calculator folders and files. Should the PC Connectivity Kit not be able to establish a connection with the calculator a "Not connected" message is displayed. In that case, check that the cable is connected firmly to the calculator and to the PC and/or check that the configurations in the calculator match with those in the PC Connectivity Kit. Use the Connectivity Kit Help to solve the problem. Then, double-click "Double-click to try to reconnect" in the lower right-hand window.
6. Click "Calculator" in the upper menu bar of the PC program, go to "Mode", and click "Binary".
7. Now, insert the "FluidHP for the HP 49" CD into the drive. Then, click your CD drive in the upper left-hand window.
In the upper right-hand window, the "RUN" file and the "FLHP" directory are displayed. Mark the "RUN" file clicking it and click "Edit" in the upper menu bar, and "Copy". Now, click "Home" in the lower left-hand window. Click "Edit" and "Paste" in the upper menu bar. The "Run" file is transferred to the HP49 "Home" directory.
8. In the HP49 "Home" directory, create the "FLHP" directory as follows:
Click "File" and "New Folder" in the upper menu bar. In the lower right-hand window, a "NEW" directory is displayed. Change this name into "FLHP".
9. Double-click "FLHP" in the upper window. Mark all files clicking on "Edit" and "Select all" in the upper menu bar. Now, copy all files clicking "Edit" and "Copy". Double-click the "FLHP" directory in the lower window. Click "Edit" and "Paste" in the upper menu bar. All program files are transferred to the HP 49 which takes a few minutes. In a window, the transfer status is displayed. After the transfer is complete, leave the server mode pressing the <On> key on the HP49.

Now, the FluidHP program is ready for use on your pocket calculator.

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

- The link cable has not been plugged correctly in the PC and the pocket calculator.
- The pocket calculator has not been in the server mode.
- The pocket calculator's memory capacity available is too small.
- The pocket calculator's batteries are flat.
- An inappropriate serial port has been set (menu point "Calculator" and "Comm settings...").

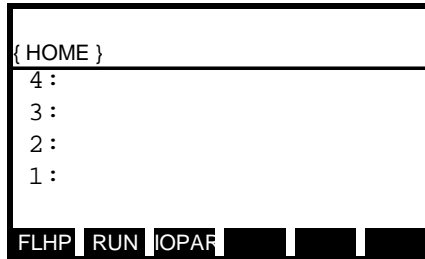
Please note.

The "RUN" file and the "FLHP" directory have to be loaded entirely into the "HOME" directory of your pocket calculator. Please do not rename or copy these files into another directory.

3.2 Starting FluidHP

Change into the "HOME" directory of your HP49 pressing <↵> and <UPDIR>. Repeat if the "HOME" directory is not displayed in the upper screen part.

Now, press <VAR> and the files of this directory are displayed in the lower bar of the HP49 screen. Press the function button below "RUN" (buttons <F1> to <F6>), and <EXE> to start FluidHP.



Should "RUN" not be visible, since more than 6 objects are in the bar, press <NXT> to view the next objects. Repeat this as often as necessary. Should the "RUN" item not exist install FluidHP again.

The menu for the selection of FluidHP functions of is displayed after the program has been started.

Please note.

There are three additional options in the function selection menu. They are available via the <▲> and <▼> cursor keys. Confirm your selection with the function button below "OK".

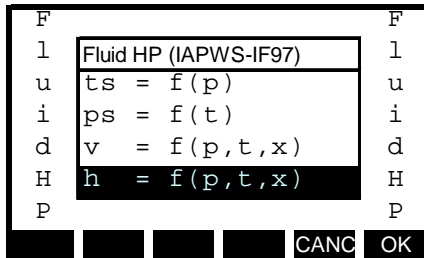
- "reset vars" All temporary variables for the in- and output can be deleted. Your HP49 deletes all values saved from calculations that were executed previously.
- "help" Short help menu and details on the FluidHP functions' range of validity.
- "about" Information on the program and the author.

3.3 Example: Calculate $h = f(p,t,x)$ with FluidHP

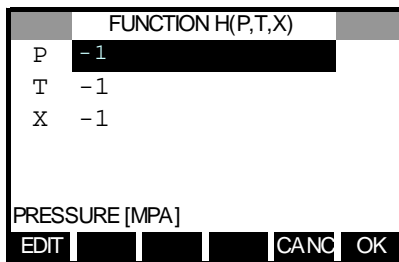
Calculate the specific enthalpy h as a function of pressure p , temperature t and vapor fraction x for the Industrial Formulation IAPWS-IF97, using FluidHP.

Do as follows:

- The function selection menu appears after you started FluidHP. Choose the " $h=f(p,t,x)$ " function with the help of the \blacktriangledown or \blacktriangle cursor key.
Confirm your selection pressing the function button below "OK".



- An input window is opened after a few seconds' time. Should you start FluidHP for the first time enter the value -1 for p , t and x .
At first, the value for pressure p in MPa is selected.



Consider the range of validity before entering the value for pressure p in MPa:

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

Superheated steam: $0.000611 \text{ MPa} \dots p = p_s(t)$ at $0 \text{ }^\circ\text{C} \dots 350 \text{ }^\circ\text{C}$

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

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

→ E.g.: Enter 10.

Confirm your input pressing the function button below "OK".

In the lower part of the screen, the current property and its appropriate unit are displayed, e.g.: "TEMPERATURE [$^\circ\text{C}$]".

- Enter a value for temperature t in $^\circ\text{C}$. Consider the range of validity before entering a value.
→ E.g. Enter 400.

Confirm your input with the help of the function button below "OK".

- The value for the vapor fraction x is now to be entered:

Since the subprograms automatically deal with the wet steam region the following specifications for the vapor fraction x are to be regarded:

Should the point of state to be calculated lie 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. Should this not apply the selected function to be calculated results in -1.

Range of validity for the wet steam region:

Temperature: from $t_t = 0$ °C up to 350 °C

Pressure: from $p_t = 0.000611$ MPa up to $p_s(t=350$ °C) = 16.5292 MPa

→ *The point of state to be calculated lies in the single-phase region. Therefore, enter the value -1 for x .*

The input window should look as follows:

```

FUNCTION H(P,T,X)
P 10
T 400
X -1
VAPOR FRACTION [KG/KG]
EDIT  CANC  OK

```

Please note.

You can enter values in any order. Choose the appropriate field with the help of the \blacktriangledown or \blacktriangle cursor key and enter the value. If you wish to delete one or more values, select these values and press $\langle \text{DEL} \rangle$. Confirm your selection with the help of the function button below "OK". All deleted values are -1 now. Start the calculation pressing the function button below "OK".

- During the calculation, the screen looks like follows:

```

FluidHP  h=f(p,t,x)
-----
is being calculated...
EDIT  CANC  OK

```


3.4 Uninstalling FluidHP

The "FLHP" directory, including all files, and the "RUN" file are to be deleted on the HP48 pocket calculator.

Do as follows:

1. Finish all running programs and go back to stack.
2. Change to the "HOME" directory pressing <↵> and <UPDIR>. Repeat if the "HOME" directory is not displayed in the upper part of the screen.
3. Open the FILE MANAGER pressing the <↵> and <FILES> buttons.
4. Open the "HOME\FLHP" directory: Choose "FLHP" with the help of the <▲> or <▼> cursor key and confirm with <ENTER>.
5. Select all files in this directory pressing <ENTER>. A check mark appears in front of each file name.
6. Delete the selected files pressing <NXT> and the function button below "PURG".
7. Open the "HOME" directory pressing <↵> and <UPDIR>.
8. Choose "FLHP:" with the <▲> or <▼> cursor key and select with <ENTER>.
A check mark appears in front of directory.
9. Choose "RUN:" with the <▲> or <▼> cursor key and select with <ENTER>.
A check mark appears in front of filename.
10. Delete the objects selected pressing the function button below "PURG".
11. Finish the variable browser with <ON>.

Please note.

- Consider that all deleted files are irretrievably lost. Do not delete thoughtlessly and secure all important programs or variables on your PC.
- For information on using the variable browser see the HP49 user's guide.

4. Program Documentation

Saturation Pressure $p_s = f(t)$

Name in FluidHP: $ps(t)$

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

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 FluidHP: $ts(p)$

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 FluidHP: $v(p,t,x)$

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

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:

- Should the point of state to be calculated lie 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. Should this not apply the selected 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

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:

$(0 \leq x \leq 1)$ 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 FluidHP: $h(p,t,x)$

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

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

- Should the point of state to be calculated lie 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. Should this not apply the selected 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

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: 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 FluidHP: $s(p,t,x)$

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

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

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

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

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:

- Should the point of state to be calculated lie 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. Should this not apply the selected 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

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: 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 FluidHP: $t(p,h)$

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

Response on faulty input values

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

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

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

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

Name in FluidHP: $t(p,s)$

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

Response on faulty input values

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

Liquid region: at values of p and s beyond the IAPWS-IF97 region 1 (Figure 1)

Steam region: at values of p and s beyond the IAPWS-IF97 region 2 (Figure 1)

Wet steam region: at values of $p > 16.5292$ MPa or $p < 0.000611$ MPa

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

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

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

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

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:

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

Error message "Out of Range!" 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 FluidHP: $x(p,s)$

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

Response on faulty input values

Should the point of state to be calculated lie in the single-phase region the result $x(p,h) = -1$ occurs for the following input values:

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

Error message "Out of Range!" 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 FluidHP: $\eta(p,t,x)$

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

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

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

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

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

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

Should the point of state to be calculated lie within the single-phase region (of liquid or superheated steam) enter the value $x = -1$. Pressure p and temperature t are given.

Should the point of state to be calculated be saturated liquid $x = 0$ has to be entered as vapor fraction. Should the point of state to be calculated be saturated vapor $x = 1$ has to be entered as vapor fraction. A calculation of values of x between 0 and 1 is not possible.

When calculating saturated liquid and saturated vapor it is adequate to enter either the given value of t and $p = -1$, or the given value of p and $t = -1$, and (in both cases) the value of x ($x = 0$ or $x = 1$). If p and t and x are entered, the program considers p and t to meet the vapor-pressure curve. Should this not apply the selected 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

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

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

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

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

Name in FluidHP: $\lambda(p,t,x)$

Input

p - pressure p in MPa

t - temperature t in °C

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

Output

$\lambda(p,t,x)$ - thermal conductivity λ in W/(m K)

Range of validity

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

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

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

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

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

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

Should the point of state to be calculated lie within the single-phase region (of liquid or superheated steam) enter the value $x = -1$. Pressure p and temperature t are given.

Should the point of state to be calculated be saturated liquid $x = 0$ has to be entered as vapor fraction. Should the point of state to be calculated be saturated vapor $x = 1$ has to be entered as vapor fraction. A calculation of values of x between 0 and 1 is not possible.

When calculating saturated liquid and saturated vapor it is adequate to enter either the given value of t and $p = -1$, or the given value of p and $t = -1$, and (in both cases) the value of x ($x = 0$ or $x = 1$). If p and t and x are entered, the program considers p and t to meet the vapor-pressure curve. Should this not apply the selected 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

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

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

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]

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

Name in FluidHP: 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 calculations for saturated liquid and saturated vapor

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

Should the point of state to be calculated lie within the single-phase region (of liquid or superheated steam) enter the value $x = -1$. Pressure p and temperature t are given.

Should the point of state to be calculated be saturated liquid $x = 0$ has to be entered as vapor fraction. Should the point of state to be calculated be saturated vapor $x = 1$ has to be entered as vapor fraction. A calculation of values of x between 0 and 1 is not possible.

When calculating saturated liquid and saturated vapor it is adequate to enter either the given value of t and $p = -1$, or the given value of p and $t = -1$, and (in both cases) the value of x ($x = 0$ or $x = 1$). If p and t and x are entered, the program considers p and t to meet the vapor-pressure curve. Should this not apply the selected 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

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

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

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

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