

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

**FluidHP for the  
HP 48 Pocket Calculator**

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

## FluidHP for the HP 48 Pocket Calculator

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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 "FluidHP for the HP 48" 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.

FluidHP48\_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 <sup>3</sup> /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  $590 \text{ °C} \dots 800 \text{ °C}$

### 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.

(IAPWS-IF97 vapor-pressure curve:                 $t = 0\text{ °C} \dots 350\text{ °C}$   
     $p = 0.000611\text{ MPa} \dots p_S(t = 350\text{ °C}) = 16.5292\text{ MPa}$ )

#### **Please note.**

Should the calculation result in -1 values have been entered beyond the IAPWS-IF97 scope respectively do not define a point of state.

For further information on each function and its scope see software documentation chapter 4.

## 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].

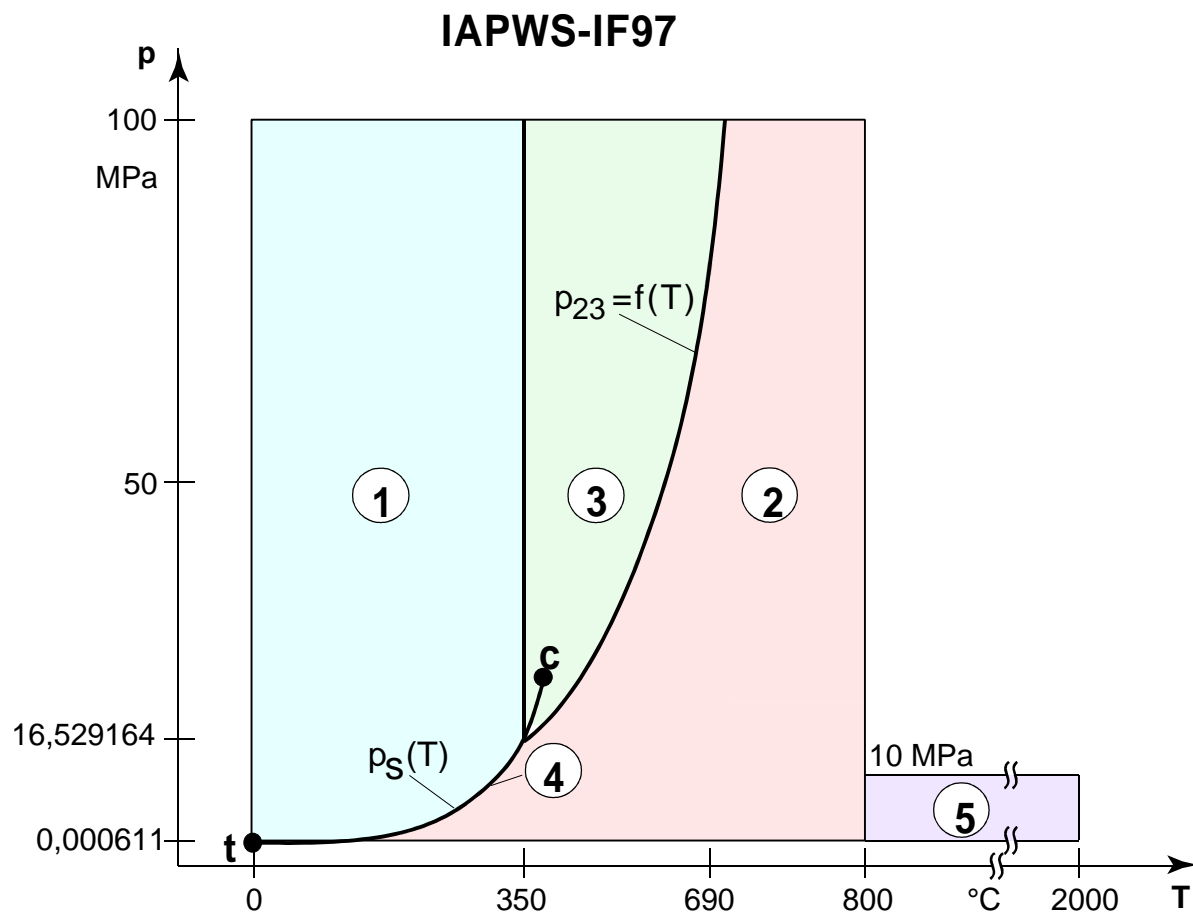
Figure 1 displays the range of validity of the new Industrial Formulation's equation theorem, fully named

"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:** Entire IAPWS-IF97 range of validity

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 onto the HP48 Pocket Calculator

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.




Yellow Computing Computersysteme GmbH offers the required link software and the link cable as *Software Kit Transfile WIN 48* which can be requested from Böttcher Datentechnik GmbH (<http://www.boettcher-datentechnik.de/>).

The following description is valid for the



Transfile WIN 48®



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




1. Connect the HP48 with the computer: Plug the link cable in a free serial port of the computer (usually COM2) and the 4-pole-connector in the pocket calculator. When doing so, switch off both devices.
2. Switch on the PC and start the Transfile WIN 48® link program. A twice split window is displayed on your computer where the PC directory is shown on the left-hand side and the "No Connection" message on the right-hand side.
3. Click the "HP 48" menu item, and "Transferparameters...". Here, select the serial port which is connected to the link cable (usually COM2) and select 9600 Baud as data transfer rate. Now, click "OK" to leave the two windows.
4. The HP48 pocket calculator is now prepared to transfer the data. Push the <ON> button in order to switch on the pocket calculator.

In order to check whether there is enough memory capacity available press the following buttons one after another: <  > <  > <  >.

In the stack, the available memory capacity of, e.g., layer 1 is indicated (in bytes). For the FluidHP transfer 25 Kbytes are necessary to load the data into the HP48 pocket calculator. Additionally, 2 Kbytes are necessary to execute FluidHP. Altogether, there should be at least 28 Kbytes of memory capacity available. 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.)

Set the HP48 directory to "HOME\", pressing <  > and <  >.

Then start the server mode, pressing <  > and <  >.

In the following menu, choose "Start Server" with the help of the <  > or <  > cursor key and confirm your selection with <  >.

The pocket calculator is waiting to be connected with the PC. "Awaiting Server Cmd." is displayed on the screen.

5. On your computer, click the "HP 48" menu item, and "Connect" in order to connect it to the pocket calculator. On the right-hand side of the Transfile WIN48 window, the "HOME\" directory of your pocket calculator is displayed. Here, the "IOPAR" file as well as other files, if necessary, has already been listed in the current "HOME\" directory.

6. Now, FluidHP can be copied onto your pocket calculator. Insert the FluidHP CD into the computer's CD drive and click the CD drive (usually -D-) on the left-hand side of the Transfile WIN48 window. The CD contains the "FLHP" directory and the "RUN" file. Select the "RUN" file. A green check mark appears in front of the file. Press the "Shift" key on the keyboard and select the "FLHP" directory. The "RUN" file and the "FLHP" directory now have a green check mark. Click the "File" and "Copy" menu items in order to start the data transfer which approximately takes two or three minutes. The "RUN" file and the "FLHP" directory include all files that are transferred to the HP48.
7. The hourglass in the upper right corner of the pocket calculator's display disappears as soon as the transfer is complete. Leave the server mode pressing <ON> on your pocket calculator. The pocket calculator's stack is now displayed which indicates the memory capacity available on, e.g., layer 1 (in Byte).

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



- The link cable between the PC and the pocket calculator has not been plugged in properly.
- The pocket calculator has not been on the server mode.
- The pocket calculator's free memory capacity is too small.
- The pocket calculator's batteries are flat.
- A wrong serial port has been set (under "HP 48" menu item, and "Transferparameters...").


**Please note.**

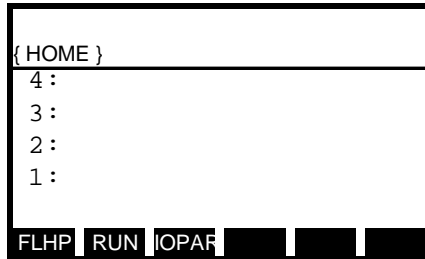
- In several cases, the Transfile WIN48® stops after transferring data with the message: "Pocket Calculator not ready". Ignore this and other messages as the data transfer has been successful anyway. However, you will not be informed about memory capacity still available when leaving the server mode. The FluidHP program has to be installed again, if there are problems with the FluidHP application.
- 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

Set the HP48 directory to "HOME\", pressing <  > and <  >.



Press <  >. The files of this directory are listed in the lower bar of the HP48 display. Press the function button below the "RUN" entry (buttons <A> to <F>) in order to start FluidHP on your HP48 pocket calculator.



Should "RUN" not be visible, since more than six objects are listed in the bar, press <  > 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 <  > cursors keys. Confirm your selection with the function button below "OK".

- |              |   |
|--------------|---|
| "reset vars" | All temporary variables for the in- and output can be deleted.<br>Your HP48 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.  |

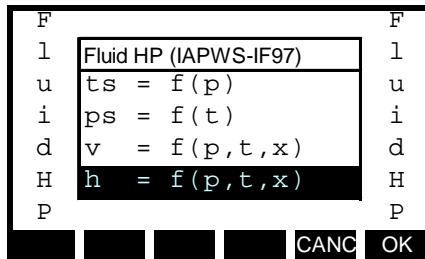
### 3.3 Example: Calculate $h = f(p,t,x)$ with FluidHP

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:

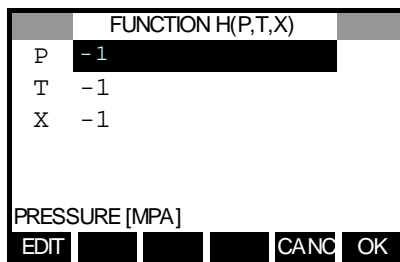
The function selection menu appears after you started FluidHP. Choose the " $h=f(p,t,x)$ " function with the help of the  $\blacktriangledown$  or  $\blacktriangle$  cursor key.

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

```

- The result for  $h$  in kJ/kg is displayed with an according audio signal.

```

FluidHP  h=f(p,t,x)
-----
h= 3097.38 kJ/kg
-> vapor region

MENU  STO  EXIT

```



→ In this example, the result is  $h=3097.38$  kJ/kg.

The calculation of  $h = f(p,t,x)$  is finished.

Now, there are three opportunities:

1. Finish FluidHP with saving the calculation result in stack layer 1:. Here, you can save or use the result for other calculations. In order to do so, press the function button below "STO".
2. Finish FluidHP without saving the result in the stack. In order to do so, press the function button below "EXIT".
3. Go back to the function menu. Here, further calculations can be executed, or information on the program and the author are available. In order to do so, press the function button below "MENU".




















**Please note.**

- Do not press other buttons than the described ones while the result is displayed. Otherwise, you call the stack, with FluidHP still active in the background and reserving memory capacity, which creates other problems. This is indicated by "HALT" that is displayed in the upper right edge of the HP48 screen. In this case, press <  > and <  > to continue the FluidHP program.
- Do not save or delete variables or programs in the "FLHP" directory.

### 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 <  >.
3. Open the variable browser, pressing the <  > and <  > buttons.
4. Open the "HOME\FLHP\" directory, pressing the function button "CHOOS", choose "FLHP" with the help of the <  > or <  > cursor key, and confirm with <  >.
5. Select all files in this directory, pressing <  > and the function button below " $\sqrt{\text{CHK}}$ ". A check mark appears in front of each file name.
6. Delete the files selected with <  > and the function button below "PURG".
7. Open the "HOME\" directory with <  >, press the function button below "CHOOS", choose "HOME" with the <  > or <  > cursor key, and confirm with <  >.
8. Choose "FLHP:" with the <  > or <  > cursor key, and select with the function button below " $\sqrt{\text{CHK}}$ ". A check mark appears in front of the file name.
9. Choose "RUN:" with the <  > or <  > cursor key and select with the function button below " $\sqrt{\text{CHK}}$ ". A check mark appears in front of the file name.
10. Delete the objects selected with <  > and the function button below "PURG".
11. Finish the variable browser with <  >.

**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 HP48 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]

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

**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 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**

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]

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

**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]

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

**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]

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

**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]

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

**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  $\eta$  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  $\rho$  or  $v$ : [1], [2], [3], [4], [5]

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

**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  $\lambda$  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° C or t < 0° C or

(x = 0 or x = 1) at t = -1 and p > 16.5292 MPa or p < 0.000611 MPa or

at p > 16.5292 MPa or p < 0.000611 MPa

and t > 350° C or t < 0° C

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

**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 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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