HOCHSCHULE
University
of
Applied Sciences
ZITTAU/GÖRLITZ

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

FluidHP for Pocket Calculator HP 49

Prof. Dr.-Ing. habil. H.-J. Kretzschmar
Dr.-Ing. I. Stöcker
Dipl.-Ing. (FH) T. Hellriegel
Cand.-Ing. (FH) C. Heinrich
R. Krause

Faculty of Mechanical Engineering
Department of Thermodynamics

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

FluidHP
for Pocket Calculator HP 49

Contents

Faculty of Mechanical Engineering
Department of Technical Thermodynamics
Prof. Dr.-Ing. habil. H.-J. Kretzschmar
Dr.-Ing. I. Stoecker
Tel.: 03583-61-1846 or -1881
Fax: 03583-61-1847
E-mail: hj.kretzschmar@hs-zigr.de
Internet: http://thermodynamics.hs-zigr.de

0. Package Contents

Disk FluidHP including the following files:

/FLHP	- Directory including program files of FluidHP.
RUN	- RUN file.
FluidHP_49G_LibIF97_Eng_Doku.pdf	- User´s Guide

1. Overview of Thermophysical Property Calculations

1.1 Range of Validity and Structure of Libraries

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" in September 1997 [1], [2], [3].

In this users' guide, it will be abbreviated as IAPWS-IF97 or only IF97. This new industrial standard should be used in acceptance and calculations of guarantee of power facilities and plants working with water or steam worldwide. The IF97 Formulation replaces the former Industrial Formulation IFC-67 [12].

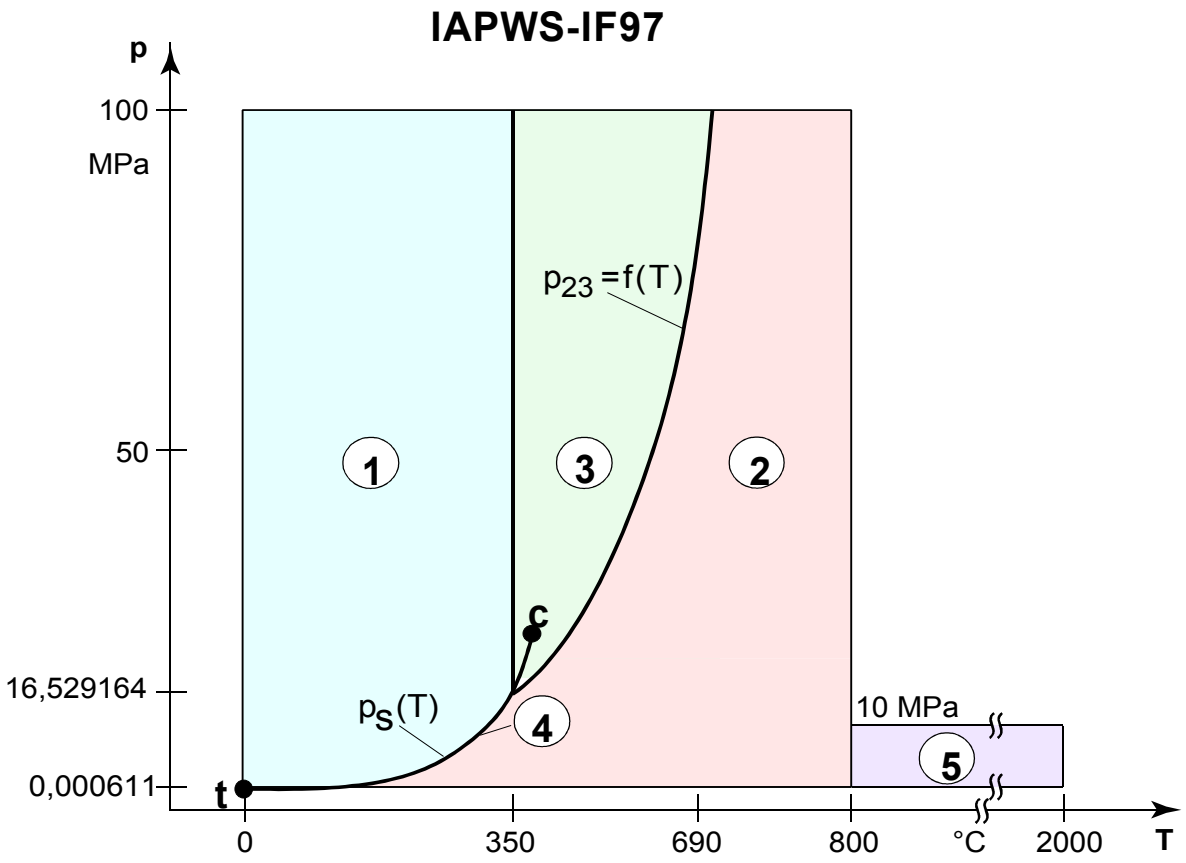


Figure 1: Range of Validity of the IF97

The range of validity of the IF97 is divided into five calculation regions. Each of the calculation regions contains its own equations of state. They are described in detail in the official Release of the IAPWS [1] and in the publications by *Wagner et al.* [2] and [3].

The present version of FluidHP cannot be used in the entire range of validity. Calculations are possible in region 1 and 2 and wet steam region until pressure 16.529164 MPa (figure1).
Calls to the necessary equation for each calculation region are incorporated within the program.

1.2 Functions for the IAPWS-IF97

Functional Dependence	Function Name in FluidHP	Property or Function	Units
$p_s = f(t)$	ps=f(t)	Saturation pressure from temperature	MPa
$t_s = f(p)$	ts=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)
$c_p = f(p,t,x)$	cp=f(p,t,x)	Specific isobaric heat capacity	kJ/(kg·K)
$\lambda = f(p,t,x)$	λ=f(p,t,x)	Thermal conductivity	W/(m·K)
$\eta = f(p,t,x)$	η=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: dryness 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: dryness 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: region 1 and 2 of the IF97 including wet steam (figure 1)

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

Region 2: 0.000611 MPa...$p = p_s(t)$ for 0 °C...350 °C

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

0.000611 MPa...100 MPa for 590 °C... 800 °C

Comment on the dryness fraction x and calculations for wet steam

Because wet steam is handled automatically, the following cautions regarding the input value of the vapor fraction x should be noted:

When the point to be calculated is in the single phase regions (liquid or superheated vapor), the pressure p and temperature t are given and the value -1 has to be entered for x .

When the point to be calculated is in wet steam, values between 0 and 1 have to be entered for x (the value 0 for saturated liquid, the value 1 for saturated vapor).
For wet steam, either the given value for t and p = -1 or the given value for p and t = -1 and (in both cases) the value for x between 0 and 1 have to be entered. For wet steam, if p and t and x are entered, the program tests whether p and t correspond to the saturation line. If this is not true, the calculated property will be -1.
(Saturation line of the IF97: t = 0 °C ... 350 °C
p = 0.000611 MPa ... p_S(t=350 °C) = 16.5292 MPa)

Note !

If the input values lie outside the range of validity of the IAPWS-IF97 or they do not define a unique state point, the result for the calculated function will always be -1.

The menupoint "help" includes the range of validity.

2. Application of FluidHP

2.1 Installing FluidHP

The program FluidCASIO will be copied from the PC to the calculator using a special Link Program and the appropriate Link Cable.

Normally, the Link Program and the Link Cable is attached to the pocket calculator. Is not it, it can be purchased in a specialized trade or requested at Böttcher Datentechnik GmbH http://www.boettcher-datentechnik.de/.

The following description refers to the link program

PC Connectivity Kit 3.0 ®,

which should already be installed. Steps for data transfer using other link programs can be taken from online helps or instructions belonging to link software.

1. Connect HP49 with PC: Pluck in the link cable in a free serial interface of the PC (COM1 or COM2) and in the Pocket Calculator. Both units should be switched off there.
2. To prepare the pocket calculator for data transfer, push button <ON> to switch on the pocket calculator.
3. To find out if enough free user memory is available, push the following buttons one after the other: <↰> and <FILES>. The FILE MANAGER appears on screen. In the directory “Home”, you should have at least 28 Kbytes of free user memory to run FluidHP. Now, leave this menu with the key <ON>.

   If less memory is free, delete old programs and variables or carry out a memory reset. User guide of your pocket calculator includes hints for deleting.
4. Start server mode by pushing the key <APPS>. Then choose "2. I/O functions.." and confirm with “OK” (the key <F6>).

   Now, choose "6. Start Server" and confirm with "OK". The message "Awaiting Server Cmd." appears in display.
5. Switch on PC and start link program *PC Connectivity Kit 3.0* ®. In some cases, the menu "Communication settings" is shown:

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

6. After a short report about the connection to the calculator, the window "HP Graphing Calculator PC ..." is shown on the PC-screen. The upper section displays the folders and files on the PC and the lower section displays the folders and files on the calculator.

The "Not connected" message is displayed when the PC Connectivity Kit cannot establish a connection with the calculator. In such a case, check that the cable is connected firmly to the calculator and to the PC and/or check that the configurations on the calculator match those on the PC Connectivity Kit. Use the Connectivity Kit Help to solve the problem. Then, doubleclick in the lower right window on "Doubleclick to try to reconnect".

7. Click in the upper menu bar of the PC program on "Calculator", go to "Mode" and click on "Binary".
8. Now, insert the diskette FluidHP into the PC. Then, click in the upper left window on the letter of your disk drive.

   In the upper right window, the file "RUN" and the directory "FLHP" are displayed. Mark the file "RUN" by clicking it and click in the upper menu bar on "Edit" and then on "Copy". Now, click in the lower left window on "Home". Click in the upper menu bar on "Edit" and then on "Paste". The file "Run" will transfer in the directory "Home" on HP49.
9. Then, create the directory "FLHP" into "Home" on HP49 as follows: Click in the upper menu bar on "File" and then on "New Folder". In the lower right window a directory "NEW" appears. Change this name into "FLHP".
10. Doubleclick in the upper window on "FLHP". Mark all files by clicking in the upper menu bar on "Edit" and then on "Select all". Now, copy all files by clicking on "Edit" and then on "Copy". Doubleclick in the lower window on the directory "FLHP" and click in the upper menu bar on "Edit" and then on "Paste". All program files will transfer on HP 49. The transfer lasts a few minutes. A window report about the status of the transfer. After finishing the transfer leave the server mode by pushing the key <On> on the HP49.

    Now, the program FluidCASIO is on your pocket calculator.

In case copy doesn't work, the following are error possibilities:

- Link cable is not correctly connected with PC and pocket calculator
- Pocket calculator is not in server mode
- Free user memory of pocket calculator is too small
- Batteries of pocket calculator are worn out
- A wrong serial port was set (menupoint "Calculator" and "Comm settings...").

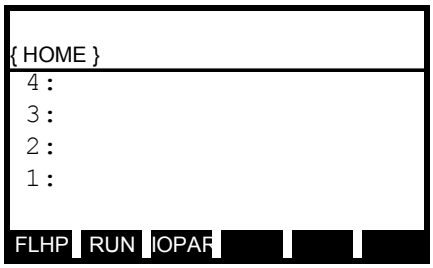
Hint:

- File "RUN" and directory "FLHP" including all files must be copied in directory "HOME\" of your pocket computer. Please, don't copy these files in another directory and don't rename these files.

2.2 Start FluidHP

Canche into directory "HOME" of your HP49 by pushing <↰ > and then <UPDIR>. Repeat this, if the directory "HOME" are not shown in the upper part of the display.

Now, push <VAR> and files in this directory appear on the lower edge of HP49 display. Push function button under object "RUN" (buttons <F1> until <F6>) and then push <EXE> to start FluidHP.



Should "RUN" not be visible, because more than 6 objects are in this directory, push <NXT> to show the next objects. Repeat this as often as it will be necessary. If object "RUN" doesn't exist, install FluidHP new.
The menu for function selection of FluidHP appears after start.

Hint:

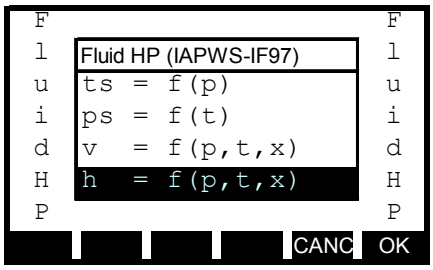
- There are 3 additional options in menu of function selection. You can reach this by cursor <▲> or <▼>. Confirm selection with function button under "OK".

"reset vars"	All temporary variables for in- and output can be deleted. Your HP48 forgets all saved values of calculations that were taken previously.
"help"	Short help and description of range of validity of FluidHP functions.
"about"	Information about program and author.

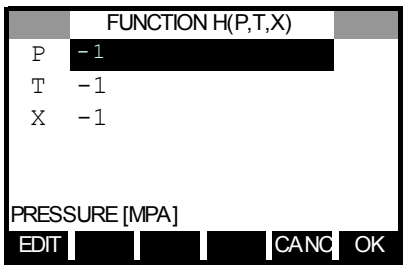
2.3 Example: Calculation of h = f(p,t,x) with FluidHP

The specific enthalpy h as a function of pressure p, temperature t and dryness fraction x can be calculated for the Industrial-Formulation IAPWS-IF97 [1,2,3] using FluidHP. To do this, the following steps must be completed:

- The menu for functionselection appears after start of FluidHP. Choose function "**h=f(p,t,x)**" with cursor <▼> or <▲>.
  Confirm selection with push functionbutton under "OK".



- An input window opens after a short moment. If you start FluidHP for the first time, value -1 has entered for p, t and x.
  At first, value for pressure p in MPa is highlighting.



  Note the range of validity before you enter pressure p in MPa:
  Liquidregion: p= p_S(t) ... 100 MPa for 0 °C ... 350 °C

  Superheated steam: 0.000611 MPa ... p=p_S(t) für 0 °C ... 350 °C

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

  0.000611 MPa ... 100 MPa for 590 °C ... 800 °C

  → *e.g. ... enter 10*

  Confirm your input with function button under "OK".

- It appears as a hint: "TEMPERATURE [°C]". Enter temperature in °C in this field. Note the range of validity before you enter temperature in °C.

  → *e.g. ... enter 400*

  Confirm your input with function button under "OK".

- The value for vapor fraction x can now be entered:

  Because wet steam is handled automatically, the following cautions regarding the input value of the vapor fraction x should be noted:

  When the point to be calculated is in the single phase regions (liquid or superheated vapor), the pressure p and temperature t are given and the value -1 has to be entered for x .
  When the point to be calculated is in wet steam, values between 0 and 1 have to be entered for x (the value 0 for saturated liquid, the value 1 for saturated vapor).

  For wet steam, either the given value for t and p = -1 or the given value for p and t = -1 and (in both cases) the value for x between 0 and 1 have to be entered. For wet steam, if p and t and x are entered, the program tests whether p and t correspond to the saturation line. If this is not true, the calculated enthalpy will be -1.

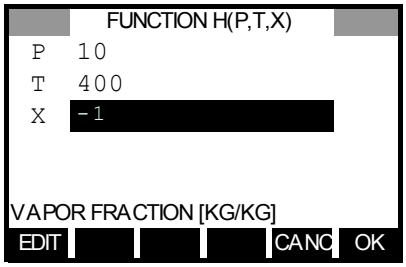
  Range of validity for wet steam region:

  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 which should be calculated is situated in the single phase region. Therefore enter value -1 for x.*

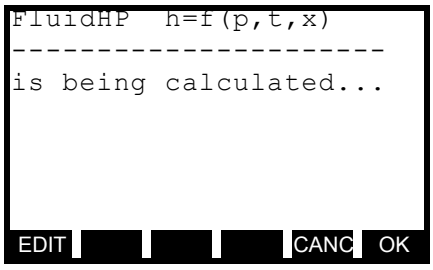
  The input window is as follows:



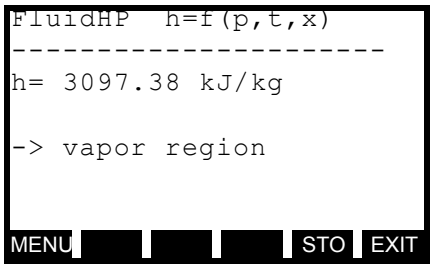
Hint:

  You can enter values in any order. Choose appropriate field with cursor <▼> or <▲> and enter value. When you want to delete one or more values, choose these values and push <DEL>. Confirm your selection with function button under "OK". All deleted values are -1 now.

- Start calculation with function button under "OK".
- During the calculation, the followed is shown on display:



- Result for h in kJ/kg appears on display and there will be a short bleep sound.



→ *Result is h=3097.38 kJ/kg in this example*.

Calculation of h = f(p,t,x) finished.

Now there are three selections:

1. You finish program FluidHP and the result of your calculation was taken over in stack in layer 1:. There, you can save or use the result for other calculations. Therefore, push functionbutton under "STO".
2. You finish program FluidHP without taking over the result in the stack. Push functionbutton under "EXIT".
3. Go back to menu of functions. Here, further calculations can be done or information about the program or author can be reached. Push functionbutton under "MENU".

Hint:

- Don't push other buttons while the result is shown on display as described buttons. Otherwise, you reach the stack. But program FluidHP is still active in background and reserve user memory, which creates other problems. You will recognize this by "HALT" appearing in the upper right edge of the display state of your HP49. In this case, push <↰> and <CONT> to continue program FluidHP.
- Don't save or delete variables or programs in directory "FLHP".

2.4 Removing FluidHP

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

Fulfil the following steps:

1. Finish all running programs.
2. Change to directory "HOME" by pushing <↰> and <UPDIR>. Repeat this, if the directory "HOME" are not shown in the upper part of the display.
3. Open FILE MANAGER by pushing buttons <↰> and <FILES>.
4. Open Directory "HOME\FLHP": Choose "FLHP" by Cursor <▲> or <▼> and confirm with <ENTER>.
5. Highlight all files in this directory by pushing <ENTER>. A mark appears in front of each filename.
6. Delete highlight files by <NXT> and function button under "PURG".
7. Open directory "HOME" by pushing <↰> and <UPDIR>.
8. Choose "FLHP:" with cursor <▲> or <▼> and highlight with <ENTER>. A mark appears in front of directory.
9. Choose "RUN:" with cursor <▲> or <▼> and highlight with <ENTER>. A mark appears in front of filename.
10. Delete highlighted objects by pushing function button under "PURG“.
11. Finish variable browser with <ON>.

Hint:

- Note, all deleted files are irretrievable if lost. Don't delete thoughtlessly and secure all important programs or variables on your PC.
- Information about using the variable browser is written in your HP49 userguide.

3. Program Documentation for Water and Steam

Saturation Pressure $p_s = f(t)$

Name in FluidHP: ps=f(t)

Input

t - Temperature t in °C

Output

ps - Saturation pressure p_s in MPa

Range of validity

from t_t = 0 °C to t_c = 350°C

Reaction for wrong input

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

t < 0 °C or t > 350°C

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

Saturation Temperature $t_s = f(p)$

Name in FluidHP: ts=f(p)

Input

p - Pressure of p in MPa

Output

ts - Saturation temperature t_s in °C

Range of validity

from p_t = 0.000611 MPa to p = 16.5292 MPa

Reaction for wrong input

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

p < 0.000611 MPa or p > 16.5292 MPa

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

Specific Volume v = f(p,t,x)

Name in FluidHP: v=f(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 - Specific volume v in m^3/kg

Range of validity

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

Steam region : 0.000611 MPa...p=p_s(t) for 0 °C...350 °C
0.000611 MPa...p_{23}(t) = p(s=5.2 kJ/(kg K) for 350 °C... 590 °C
0.000611 MPa...100 MPa for 590 °C... 800 °C

Comment on the vapor fraction x and calculations for wet steam

Because wet steam is handled automatically, the following cautions regarding the input value of the vapor fraction x should be noted:

When the point to be calculated is in the single phase regions (liquid or superheated vapor), the pressure p and temperature t are given and the value -1 has to be entered for x.

When the point to be calculated is in wet steam, values between 0 and 1 have to be entered for x (the value 0 for saturated liquid, the value 1 for saturated vapor).

For wet steam, either the given value for t and p = -1 or the given value for p and t = -1 and (in both cases) the value for x between 0 and 1 have to be entered. For wet steam, if p and t and x are entered, the program tests whether p and t correspond to the saturation line. If this is not true, the calculated property will be -1.

Wet steam region: t = 0 °C ... 350 °C
p = 0.000611 MPa ... 16.5292 MPa

Reaction for wrong input

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

One phase region: the entered parameters are outside of the above mentioned range of validity (x = -1)

Wet steam region:
($0 \le x \le 1$) at p= -1 and t > 350 °C or t < 0 °C or
at t = -1 and p > 16.5292 MPa or p < 0.000611 MPa or
at p > 16.5292 MPa or p < 0.000611 MPa
and t > 350° C or t < 0° C
at | t-t_s(p) | > 0.1 K

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

Specific Enthalpy h = f(p,t,x)

Name in FluidHP: h=f(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 - Specific enthalpy h in kJ/kg

Range of validity

Liquid region : p= p_s(t)...100 MPa for 0 °C...350 °C
Steam region : 0.000611 MPa...p=p_s(t) for 0 °C...350 °C
0.000611 MPa...p_{23}(t) = p(s=5.2 kJ/(kg K) for 350 °C... 590 °C
0.000611 MPa...100 MPa for 590 °C... 800 °C

Comment on the vapor fraction x and calculations for wet steam

Because wet steam is handled automatically, the following cautions regarding the input value of the vapor fraction x should be noted:

When the point to be calculated is in the single phase regions (liquid or superheated vapor), the pressure p and temperature t are given and the value -1 has to be entered for x.

When the point to be calculated is in wet steam, values between 0 and 1 have to be entered for x (the value 0 for saturated liquid, the value 1 for saturated vapor).

For wet steam, either the given value for t and p = -1 or the given value for p and t = -1 and (in both cases) the value for x between 0 and 1 have to be entered. For wet steam, if p and t and x are entered, the program tests whether p and t correspond to the saturation line. If this is not true, the calculated property will be -1.

Wet steam region: t = 0 °C ... 350 °C
p = 0.000611 MPa ... 16.5292 MPa

Reaction for wrong input

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

One phase region: the entered parameters are outside of the above mentioned range of validity (x = -1)

Wet steam region: ($0 \le x \le 1$)
at p = -1 and t > 350° C or t < 0° C or
at t = -1 and p > 16.5292 MPa or p < 0.000611 MPa or
at p > 16.5292 MPa or p < 0.000611 MPa
and t > 350° C or t < 0° C
at | t-t_s(p) | > 0.1 K

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

Specific Entropy s = f(p,t,x)

Name in FluidHP: s=f(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 - Specific entropy s in kJ/(kg K)

Range of validity

Liquid region : p= p_s(t)...100 MPa for 0 °C...350 °C
Steam region : 0.000611 MPa...p=p_s(t) for 0 °C...350 °C
0.000611 MPa...p_{23}(t) = p(s=5.2 kJ/(kg K) for 350 °C... 590 °C
0.000611 MPa...100 MPa for 590 °C... 800 °C

Comment on the vapor fraction x and calculations for wet steam

Because wet steam is handled automatically, the following cautions regarding the input value of the vapor fraction x should be noted:

When the point to be calculated is in the single phase regions (liquid or superheated vapor), the pressure p and temperature t are given and the value -1 has to be entered for x.

When the point to be calculated is in wet steam, values between 0 and 1 have to be entered for x (the value 0 for saturated liquid, the value 1 for saturated vapor).

For wet steam, either the given value for t and p = -1 or the given value for p and t = -1 and (in both cases) the value for x between 0 and 1 have to be entered. For wet steam, if p and t and x are entered, the program tests whether p and t correspond to the saturation line. If this is not true, the calculated property will be -1.

Wet steam region: t = 0 °C ... 350 °C
p = 0.000611 MPa ... 16.5292 MPa

Reaction for wrong input

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

One phase region: the entered parameters are outside of the above mentioned range of validity (x = -1)

Wet steam region: ($0 \leq x \leq 1$) at p = -1 and t > 350° C or t < 0° C or
at t = -1 and p > 16.5292 MPa or p < 0.000611 MPa or
at p > 16.5292 MPa or p < 0.000611 MPa
and t > 350° C or t < 0° C
at | t-t_s(p) | > 0.1 K

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

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

Name in FluidHP: cp=f(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 - Specific Isobaric Heat Capacity c_p in kJ/kg K

Range of validity

Liquid region : p= p_s(t)...100 MPa for 0 °C...350 °C
Steam region : 0.000611 MPa...p=p_s(t) for 0 °C...350 °C
0.000611 MPa...p_{23}(t) = p(s=5.2 kJ/(kg K) for 350 °C... 590 °C
0.000611 MPa...100 MPa for 590 °C... 800 °C

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

Because wet steam is handled automatically, the following cautions regarding the input value of the vapor fraction x should be noted:

When the point to be calculated is in the single phase regions (liquid or superheated vapor), the pressure p and temperature t are given and the value -1 has to be entered for x.

When the point to be calculated is saturated liquid the value x = 0 has to be entered. In case of saturated vapour the value 1 has to be entered for x. A calculation of values between 0 and 1 is impossible.

For for saturated liquid and saturated vapor, either the given value for t and p = -1 or the given value for p and t = -1 and (in both cases) the value for x (x = 0 or x = 1) have to be entered. If p and t and x are entered, the program tests whether p and t correspond to the saturation line. If this is not true, the calculated property will be -1.

Saturated liquid and saturated vapor: t = 0 °C ... 350 °C
p = 0.000611 MPa ... 16.5292 MPa

Reaction for wrong input

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

One phase region: the entered parameters are outside of the above mentioned range of validity (x = -1)

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

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

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

Name in FluidHP: λ=f(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

λ - Thermal conductivity λ in W/(m K)

Range of validity

Liquid region :	p= p_s(t)...100 MPa for 0 °C...350 °C
Steam region :	0.000611 MPa...p=p_s(t) for 0 °C...350 °C
	0.000611 MPa...p_{23}(t) = p(s=5.2 kJ/(kg K) for 350 °C... 590 °C
	0.000611 MPa...100 MPa for 590 °C... 800 °C

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

Because wet steam is handled automatically, the following cautions regarding the input value of the vapor fraction x should be noted:

When the point to be calculated is in the single phase regions (liquid or superheated vapor), the pressure p and temperature t are given and the value -1 has to be entered for x.

When the point to be calculated is saturated liquid the value x = 0 has to be entered. In case of saturated vapour the value 1 has to be entered for x. A calculation of values between 0 and 1 is impossible.

For for saturated liquid and saturated vapor, either the given value for t and p = -1 or the given value for p and t = -1 and (in both cases) the value for x (x = 0 or x = 1) have to be entered. If p and t and x are entered, the program tests whether p and t correspond to the saturation line. If this is not true, the calculated property will be -1.

Saturated liquid and saturated vapor: t = 0 °C ... 350 °C
p = 0.000611 MPa ... 16.5292 MPa

Reaction for wrong input

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

One phase region: the entered parameters are outside of the above mentioned range of validity (x = -1)

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

References: [6], Internal calculation of ρ or v: [1], [2], [3], [4], [5]

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

Name in FluidHP: η=f(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

η - Dynamic viscosity η in MPa s

Range of validity

Liquid region : p= p_s(t)...100 MPa for 0 °C...350 °C
Steam region : 0.000611 MPa...p=p_s(t) for 0 °C...350 °C
0.000611 MPa...p_{23}(t) = p(s=5.2 kJ/(kg K) for 350 °C... 590 °C
0.000611 MPa...100 MPa for 590 °C... 800 °C

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

Because wet steam is handled automatically, the following cautions regarding the input value of the vapor fraction x should be noted:

When the point to be calculated is in the single phase regions (liquid or superheated vapor), the pressure p and temperature t are given and the value -1 has to be entered for x.

When the point to be calculated is saturated liquid the value x = 0 has to be entered. In case of saturated vapour the value 1 has to be entered for x. A calculation of values between 0 and 1 is impossible.

For for saturated liquid and saturated vapor, either the given value for t and p = -1 or the given value for p and t = -1 and (in both cases) the value for x (x = 0 or x = 1) have to be entered. If p and t and x are entered, the program tests whether p and t correspond to the saturation line. If this is not true, the calculated property will be -1.

Saturated liquid and saturated vapor: t = 0 °C ... 350 °C
p = 0.000611 MPa ... 16.5292 MPa

Reaction for wrong input

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

One phase region: the entered parameters are outside of the above mentioned range of validity (x = -1)

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

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

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

Name in FluidHP: t=f(p,h)

Input

p - Pressure p in MPa
h - Specific enthalpy h in kJ/kg

Output

t - Temperature t in °C

Range of validity

Liquid region:	IAPWS-IF97 region 1 (Figure 1)
Steam region:	IAPWS-IF97 region 2 (Figure 1)
Wet steam region:	p = 0.000611 ... 16.5292 MPa and $h'(p) \leq h \leq h''(p)$

Comment on the calculations for wet steam

The wet steam region is handled automatically. This means with reference to the given values for p and h a subroutine find out whether the condition point to be calculated lies in the one phase area (liquid or steam) or in the wet steam region. Then the concerning condition area will be calculated.

Reaction for wrong input

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

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

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

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

Name in FluidHP: x=f(p,h)

Input

p - Pressure p in MPa
h - Specific enthalpy h in kJ/kg

Output

x - 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 ... 16.5292 MPa and $h'(p) \leq h \leq h''(p)$

Comment on the calculations for wet steam

The wet steam region is handled automatically. This means with reference to the given values for p and h a subroutine find out whether the condition point to be calculated lies in the one phase area (liquid or steam) or in the wet steam region. In case of wet steam the value of x will be calculated. Is the condition point to be calculated in a one phase area the result of x will be x = -1.

Reaction for wrong input

Result x(p,h) = -1 for input values:

if the condition point to be calculated lies in the one phase area:
p > 16.5292 MPa or h < h'(p) or h > h"(p)

Error message "Out of Range!" for input values:
p < 0.000611 MPa or p > 100 MPa

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

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

Name in FluidHP: t=f(p,s)

Input

p - Pressure p in MPa
s - Specific entropy s in kJ/(kg K)

Output

t - Temperature t in °C

Range of validity

Liquid region:	IAPWS-IF97 region 1 (Figure 1)
Steam region:	IAPWS-IF97 region 2 (Figure 1)
Wet steam region:	p = 0.000611 ... 16.5292 MPa and $s'(p) \leq s \leq s''(p)$

Comment on the calculations for wet steam

The wet steam region is handled automatically. This means with reference to the given values for p and s a subroutine find out whether the condition point to be calculated lies in the one phase area (liquid or steam) or in the wet steam region. Then the concerning condition area will be calculated.

Reaction for wrong input

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

Liquid region :	at values of p and s outside region 1 of the IAPWS-IF97 (Figure 1)
Steam region:	at values of p and s outside region 2 of the IAPWS-IF97 (Figure 1)
Water steam region:	at values of p > 16.5292 MPa or p < 0.000611 MPa

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

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

Name in FluidHP: x=f(p,h)

Input

p - Pressure p in MPa
s - Specific entropy s in kJ/(kg K)

Output

x - 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 ... 16.5292 MPa and $s'(p) \leq s \leq s''(p)$

Comment on the calculations for wet steam

The wet steam region is handled automatically. This means with reference to the given values for p and s a subroutine find out whether the condition point to be calculated lies in the one phase area (liquid or steam) or in the wet steam region. In case of wet steam the value of x will be calculated. Is the condition point to be calculated in a one phase area the result of x will be x = -1.

Reaction for wrong input

Result x(p,s) = -1 for input values:

if the condition point to be calculated lies in the one phase area:
p > 16.5292 MPa or s < s'(p) or s > s"(p)

Error message "Out of Range!" for input values:
p < 0.000611 MPa or p > 100 MPa

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

4. Other Libraries of Thermodynamic Properties

The Department of Technical Thermodynamics of the University of Applied Sciences of Zittau and Görlitz offers the following software tools:

- DLL-XLA-Libraries for MS-Excel
- DLL- Libraries for MathCad
- DLL- Libraries for other applications under MS-Windows
- Source code
- Software for pocket calculators.

At the moment, libraries and programs for the following substances and formulations can be delivered:

Water IAPWS-IF97

- New Industrial Formulation, valid since September 1997 [1,2,3,4]

Water IAPWS-95

- Scientific Formulation [11] for high accuracy demands

Water IFC-67

- Previous Industrial Formulation up to September 1997 [12]

Gases and Mixtures

- Model of ideal gas for c_p = f(T) of *Baehr* [14] and *Brandt* [15]

Humid Air for variable pressure and c_p = const

- Model of ideal gas and liquid for c_p = const

Humid Air for variable pressure and c_p = f(T)

- Model of ideal gas and liquid for c_p = f(T) of *Baehr* [14] and *Brandt* [15]

5. References

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

[2] Wagner, W.; Kruse, A.:
Zustandsgrößen von Wasser und Wasserdampf.
Springer-Verlag, Berlin (1998)

[3] Wagner, W.; Cooper, J.R.; Dittmann, A.; Kijima, J.; Kretzschmar, H.-J.; Kruse, A.; Mareš, R.; Oguchi, K.; Sato, H.; Stöcker, I.; Šifner, O.; Takaishi, Y.; Tanishita, I.; Trübenbach, J.; Willkommen, Th.:
The IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam.
Journal of Engineering for Gas Turbines and Power 122 (2000) Nr. 1, S. 150-182

[4] Kretzschmar, H.-J.; Stöcker, I.; Klinger, J.; Dittmann, A.:
Calculation of Thermodynamic Derivatives for Water and Steam Using the New Industrial Formulation IAPWS-IF97.
in: Steam, Water and Hydrothermal Systems: Physics and Chemistry Meeting the Needs of Industry, Proceedings of the 13th International Conference on the Properties of Water and Steam, Eds. P.G. Hill et al., NRC Press, Ottawa, 2000

[5] Kretzschmar, H.-J.:
Mollier h,s-Diagramm.
Springer-Verlag, Berlin (1998)

[6] Revised Release on the IAPS Formulation 1985 for the Thermal Conductivity of Ordinary Water Substance.
IAPWS Sekretariat, Dooley, B., EPRI, Palo Alto CA, (1997)

[7] Revised Release on the IAPS Formulation 1985 for the Viscosity of Ordinary Water Substance.
IAPWS Secretariat, Dooley, B., EPRI, Palo Alto CA, (1997)

[8] IAPWS Release on Surface Tension of Ordinary Water Substance 1994.
IAPWS Sekretariat, Dooley, B., EPRI, Palo Alto CA, (1994)

[9] Kretzschmar, H.-J.; Stöcker, I.; Willkommen, Th.; Trübenbach, J.; Dittmann, A.:
Supplementary Equations $v(p,T)$ for the Critical Region to the New Industrial Formulation IAPWS-IF97 for Water and Steam.
in: Steam, Water and Hydrothermal Systems: Physics and Chemistry Meeting the Needs of Industry, Proceedings of the 13th International Conference on the Properties of Water and Steam, Eds. P.G. Hill et al., NRC Press, Ottawa, 2000

[10] Kretzschmar, H.-J.; Cooper, J.R.; Dittmann, A.; Friend, D.G.; Knobloch, K.; Mareš, R.; Stöcker, I.; Trübenbach, J.; Willkommen, Th.:
Supplementary Backward Equations for pressure as function of enthalpy and entropy to the Industrial Formulation IAPWS-IF97 for Water and Steam.
Journal of Engineering for Gas Turbines and Power - in preparation

[11] Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use.
IAPWS Sekretariat, Dooley, B., EPRI, Palo Alto CA, (1995)

[12] Grigull, U.:
Properties of Water and Steam in SI Units.
Springer-Verlag, Berlin (1989)

[13] Kretzschmar, H.-J.:
Zur Aufbereitung und Darbietung thermophysikalischer Stoffdaten für die Energietechnik.
Habilitation, TU Dresden, Fakultät Maschinenwesen (1990)

[14] VDI Richtlinie 4670
Thermodynamische Stoffwerte von feuchter Luft und Verbrennungsgasen.

[15] Brandt, F.:
Wärmeübertragung in Dampferzeugern und Wärmetauschern.
FDBR-Fachbuchreihe, Bd. 2, Vulkan Verlag Essen (1985)

University of Applied Sciences of Zittau and Görlitz (FH)
Department of Technical Thermodynamics
Prof. Dr.-Ing. habil. H.-J. Kretzschmar
D-02754 Zittau, Germany
Tel.: +49-3583-61-1846 Fax: +49-3583-61-1847
E-mail: hj.kretzschmar@hs-zigr.de
Internet: thermodynamics.hs-zigr.de

FluidHP for Pocket Calculator HP 49

Thermodynamic Properties of Water and Steam calculated from the industrial standard IAPWS-IF97

September 17, 2003 **1.44 MB**