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

**FluidTI  
LibIF97  
for the  
TI-84 Plus**

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

## FluidTI LibIF97 for the TI-84 Plus

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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 "FluidTI for the TI-84 Plus" CD includes the following files:

\TI-Files with the program files

- FLUIDTI.8xp
- FLUIDTI3.8xp
- FLUIDTI4.8xp
- FLUIDTI5.8xp
- FLUIDTI6.8xp

and list files

- E.8xl
- F.8xl
- G.8xl
- H.8xl

FluidTI\_TI-84\_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 FluidTI	Property or Function	Unit
$p_s = f(t)$	PS(T)	Saturation pressure from temperature	MPa
$t_s = f(p)$	TS(P)	Saturation temperature from pressure	°C
$v = f(p,t,x)$	V(P,T,X)	Specific volume	m <sup>3</sup> /kg
$h = f(p,t,x)$	H(P,T,X)	Specific enthalpy	kJ/kg
$s = f(p,t,x)$	S(P,T,X)	Specific entropy	kJ/(kg K)
$t = f(p,h)$	T(P,H)	Backward function: temperature from pressure and enthalpy	°C
$t = f(p,s)$	T(P,S)	Backward function: temperature from pressure and entropy	°C
$x = f(p,h)$	X(P,H)	Backward function: vapor fraction from pressure and enthalpy	kg/kg
$x = f(p,s)$	X(P,S)	Backward function: vapor fraction from pressure and entropy	kg/kg

**Units:**  
 $t$  in °C  
 $p$  in MPa  
 $x$  in (kg saturated steam)/(kg wet steam)

### Range of validity: IAPWS-IF97 regions 1 and 2, including wet steam

Liquid region 1:  $p = p_s(t)$ ...100 MPa at 0 °C... 350 °C

Steam region 2: 0.000611 MPa...  $p = p_s(t)$  at 0 °C... 350 °C

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

0.000611 MPa... 100 MPa at 590 °C... 800 °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 in the single-phase regions (of liquid or superheated vapor) enter -1 as a value of  $x$ . Pressure  $p$  and temperature  $t$  are given.

Should the point of state to be calculated lie in the wet steam region the value for  $x$  to be entered ranges from 0 to 1 (0 = saturated liquid, 1 = saturated vapor).

When calculating wet steam it is adequate to enter either the given value for  $t$  and  $p = -1$ , or the given value for  $p$  and  $t = -1$ , as well as the value for  $x$  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 an error message is displayed for the selected function to be calculated.

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. In this case, an error message is displayed.

## 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].

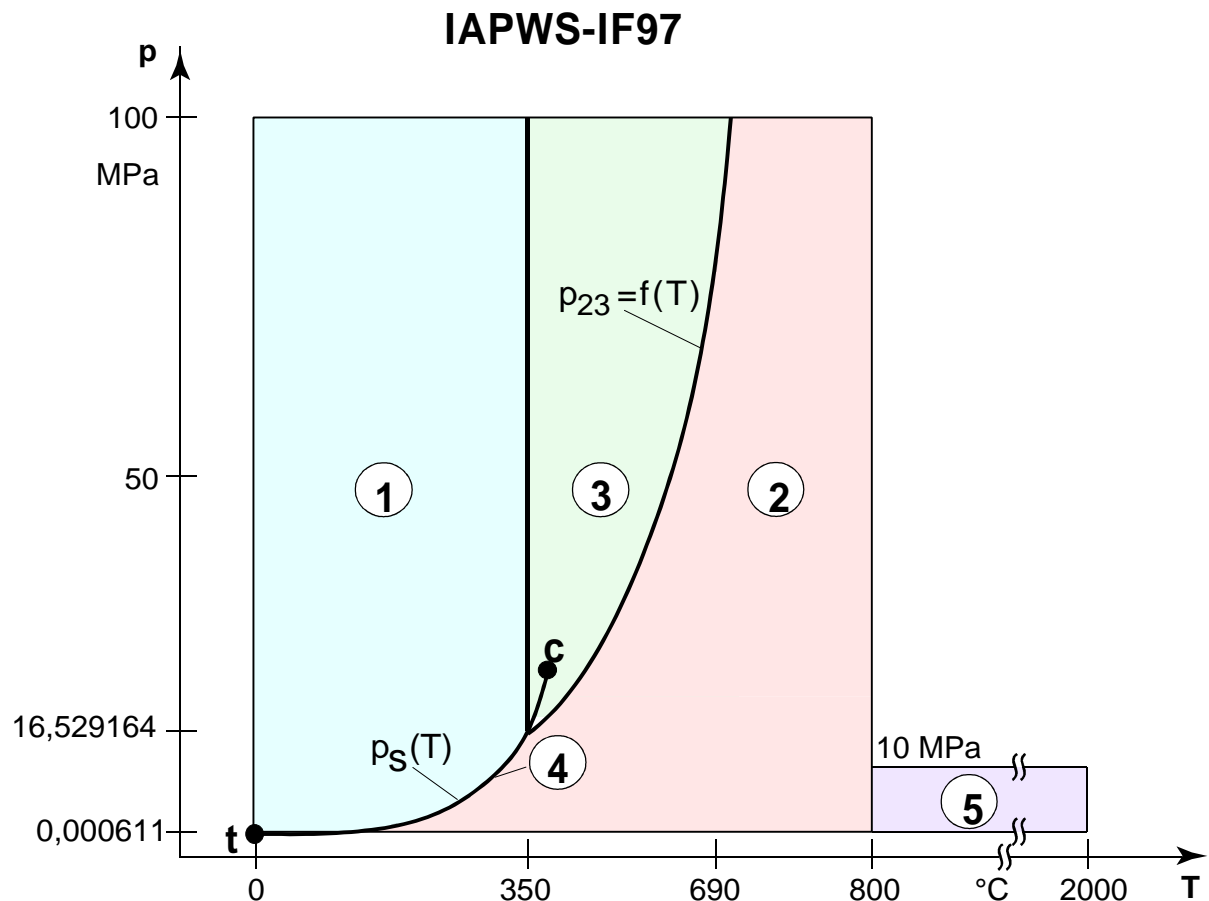
Figure 1 displays the range of validity of the new Industrial Formulation's equation theorem, fully named

"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 FluidTI 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 FluidTI for the calculation of water and steam

### 3.1 Installing FluidTI on TI-84 Plus

In order to run the FluidTI software on your pocket calculator, load the program from your computer into the calculator, using a special link program and the appropriate USB cable.

15 KB of free memory capacity (RAM) are required to load the software into the TI. For the TI-84 Plus, programs can be saved in an ARC-memory without necessarily deleting them. For further information see "Details: The TI-84 Plus flash memory" at the end of chapter 3.1.

The link program as well as the USB cable can be purchased in a TI service store or ordered at Boettcher Datentechnik GmbH (<http://www.boettcher-datentechnik.de/>).

The following description is valid for the

TI-Connect™

link program which is to be installed first into Windows® XP. (For another link program used for file transfer see the corresponding user's guide or online help.)

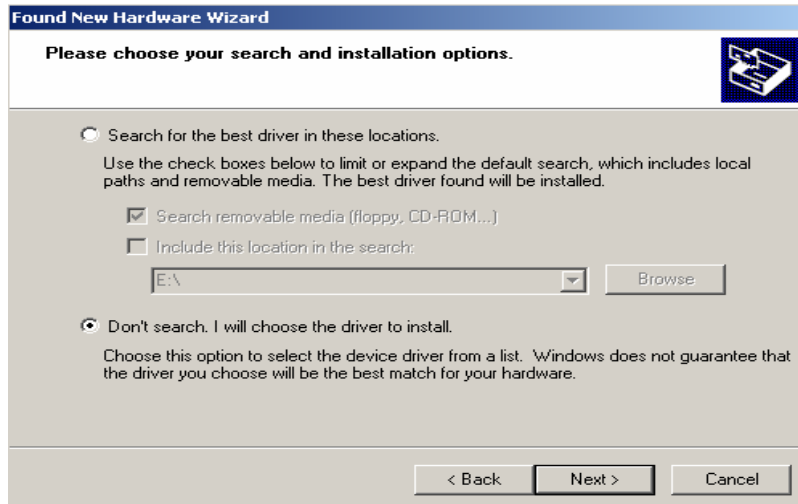
#### Installing FluidTI:

1. Connect the TI calculator with the PC as follows.  
Plug the USB cable in the TI calculator and in a free USB port of the PC.  
The TI-84 Plus switches on automatically as soon as the USB cable has been plugged in.  
The "Found New Hardware Wizard" window is opened automatically on the PC:



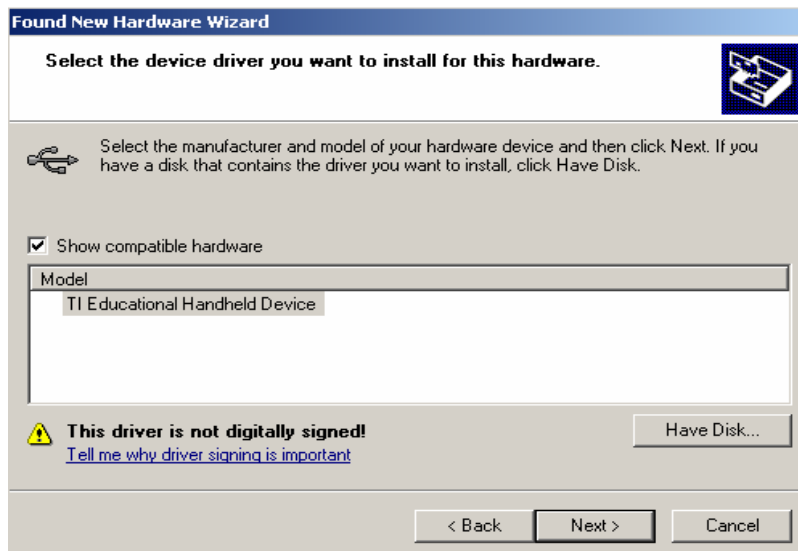
Select the "Install from a list or specific location (Advanced)" radio button and click "Next >".

2. The following window is displayed:



Select the "Don't search. I will choose the driver to install." radio button and confirm clicking the "Next >" button.

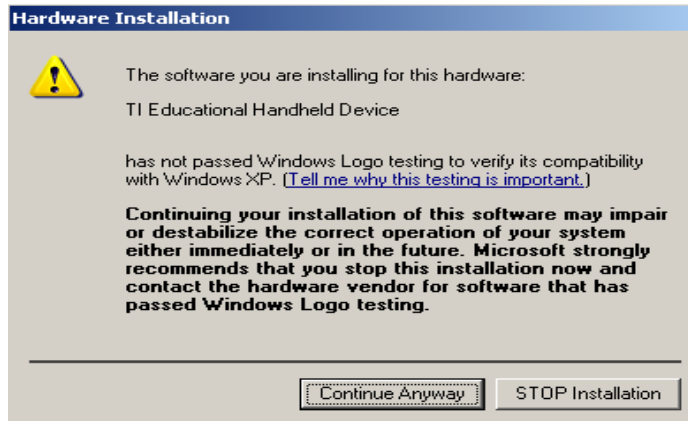
3. The next window is displayed:



If "TI Education Handheld Device" is displayed in the window below "Model", click "Next >".

If not, click the "Have Disk..." button. In the next window, search the driver files in the installation path of TI-Connect™ ("C:\Programs\TI Education\Driver Files"). Continue clicking "OK" .

4. The following window is displayed:



Click "Continue Anyway" to continue the installation.

5. The following window shows that the installation was successful:



Click the "Finish" button to close the window.

6. In case the TI-84 Plus switched off automatically, switch it on again.

**Note:** Always check whether the calculator is switched on.

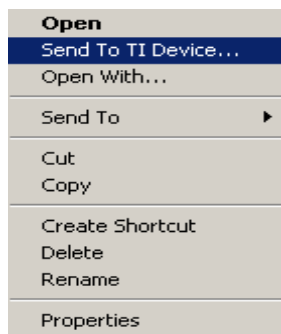
7. Insert the "FluidTI for the TI-84 Plus" CD into the drive of the PC.

8. Click "Start" and "My Computer" in the Windows task bar and select the appropriate CD drive.

Open the CD "TI-Files" folder, double-clicking it.

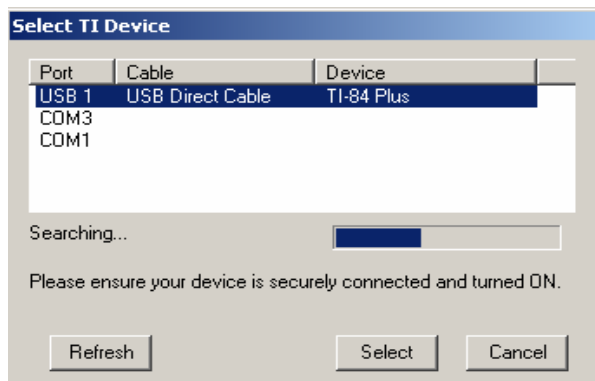
Select all files, firstly, clicking the first file with the left mouse button, secondly, pressing the "Shift" key on the keyboard, and thirdly, clicking the last file with the left mouse button while keeping the "Shift" key pressed. Now, all files are selected.

9. With the cursor on the files selected, click the right mouse button. The following window is displayed:



Select "Send to TI Device..." to send the files to the calculator.

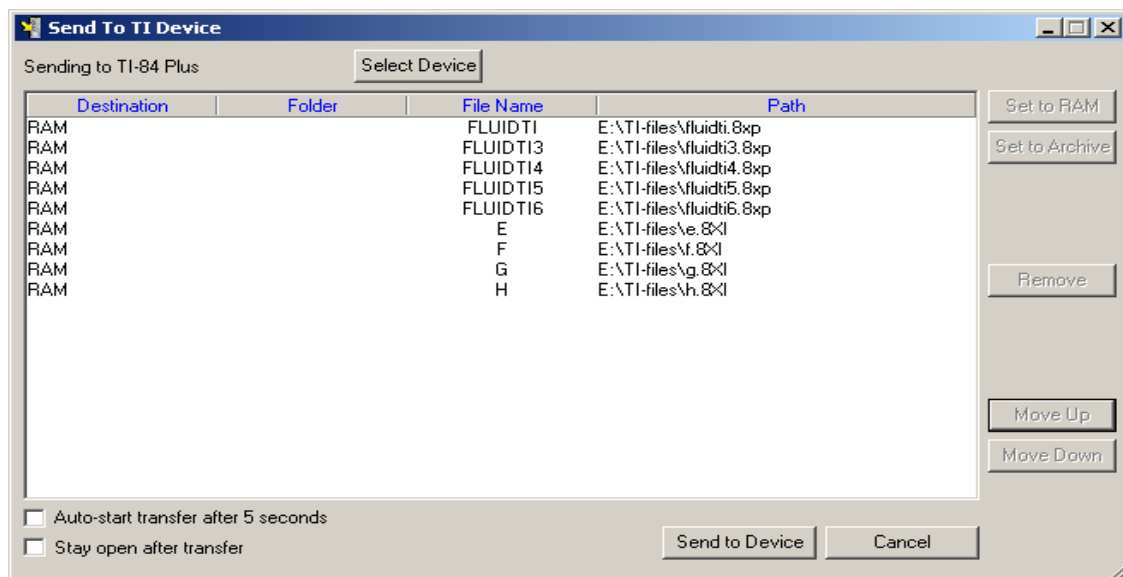
10. The following window is displayed. If it is not, continue with paragraph 11:



Below "Port", select the USB port connected with the calculator, clicking it, and click the "Select" button.

If the TI-84 Plus is not listed, switch on the calculator and try again clicking "Refresh".

11. The following window is displayed:



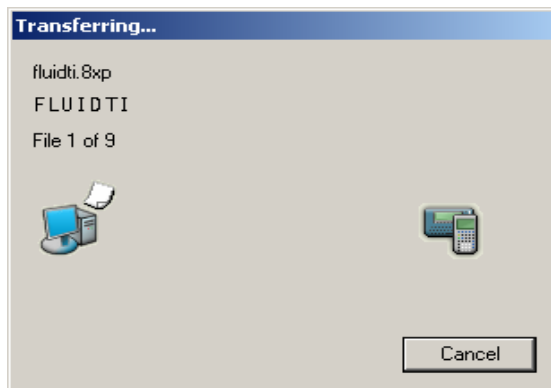
In the "Destination" column, "RAM" should be listed.

If not, select the first row clicking the first file name in the list.

Now, select "RAM" for this file in the "Destination" column. Proceed equally with the remaining files.

Click "Send to Device", in order to start the transfer.

12. The following window is displayed:



If that window is closed without an error message, the transfer was successful.

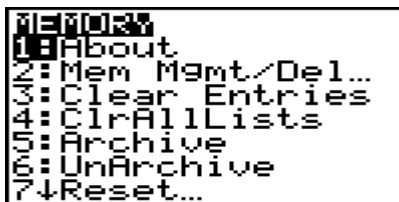
Should the files have not been copied to the pocket calculator the transfer failed due to one of the following errors:

- The USB interface could not choose for the transfer.  
Switch on the TI-84 Plus and try again.
- The USB cable has not been plugged in properly.

#### Details: The TI-84 Plus flash memory

In order to achieve more free RAM memory capacity on your TI-84 Plus by saving programs, do as follows:

1. Enter the memory menu pressing <2nd>, and <MEM> (upper the <+> key). The following screen is displayed:



2. Choose "2:Mem Mgmt/Del..." with the cursor block and confirm with <ENTER>, or press <2>. The following window is displayed:

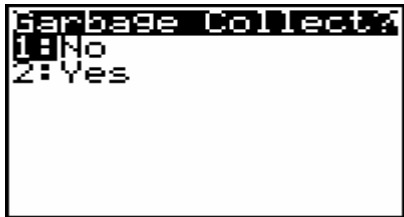


3. If the figure behind "RAM FREE" is higher than 15000, there is enough RAM memory available for the installation of FluidTI. Press <2nd>, and <QUIT> (above the <MODE> key) to return.

If there is less than 15 KB memory capacity available, see the next paragraphs.

4. Choose "7: Prgm..." and confirm with <ENTER>, or press <7>.

5. Now, all programs are listed with their memory capacity in Bytes (on the right-hand side). In the "RAM FREE" line, the RAM memory capacity available is displayed. In the "ARC FREE" line, the free archive memory is displayed. Place the cursor with the help of the cursor block in front of a program and press <ENTER> to archive it. Now, a star appears in front of the program. (Should the "Garbage Collect?" window opens instead, see paragraph 7 first.) The star symbolizes the archived state. The figure in the line of "RAM FREE" rises about the size of the archived program. Repeat the procedure until 15 KB RAM memory are available.
6. In order to un-archive a program, place the cursor in front of it and press <ENTER>. The star disappears and the program is back in the RAM memory. After you archived and un-archived programs, the following window is displayed:



7. Choose "2: YES" with the cursor block and confirm with <ENTER>, or press <2>. The procedure takes about half a minute. The pocket calculator deletes unnecessary data in the archives.

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

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

Do as follows:

- Press the <PRGM> key to open the program menu.
- Start the program choosing "FLUIDTI" with the help of the cursor block and press <ENTER> to confirm. "prgmFLUIDTI" is displayed on your calculator screen.

```
prgmFLUIDTI
```

Press <ENTER>.

- The following screen is displayed:

```
FLUIDTI
STEAMTABLES
IAPWS-IF97
VERSION FOR
STUDENTS
```

#### Note:

Should the following message be displayed the TI could not find the FLUIDTI program.

```
ERR:ARCHIVED
1:Quit
2:Goto
```

Press <ENTER> and un-archive the FLUIDTI file. In order to do so, see the information under "Details: The TI-84 Plus flash memory" at the end of chapter 3.1 .

Then, start the example again.

- Press <ENTER> for the FluidTI function menu:

```
IAPWS-IF97
1:PS(T)
2:TS(P)
3:V(P,T,X)
4:H(P,T,X)
5:S(P,T,X)
6:CONTINUE
7:END
```

- Move the cursor to "6:CONTINUE" and confirm with <ENTER>, or press <6> for further functions:

```

IAPWS-IF97
1: T(P,S)
2: T(P,H)
3: X(P,S)
4: X(P,H)
5: HLP INPUT OF X
6: ABOUT FLUIDTI
7: MENU BEGIN

```

Select "7:MENU BEGIN" and confirm with <ENTER>, or press <7> to return to the first part of the menu.

- In the first menu part, select "4:H(P,T,X)" with the cursor block and confirm with <ENTER>, or press <4> to choose the function "h(p,t,x)".

The following input window for pressure p in MPa is displayed:

```

P IN MPA =          .1
-2->TAKE THIS
P=■

```

Consider the IAPWS-IF97 range of validity:

$$p = 0.000611 \text{ MPa} \dots 100 \text{ MPa}$$

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

**Note:** In order to confirm the value displayed in the second line enter -2.

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

```

T IN °C =          100
-2->TAKE THIS
T=■

```

Consider the IAPWS-IF97 range of validity:

$$t = 0 \text{ °C} \dots 350 \text{ °C}$$

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

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

```

X IN KG/KG =          -1
-2->TAKE THIS
X=■

```

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

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

Should the point of state to be calculated lie in the wet steam region the value to be entered for  $x$  ranges between 0 and 1 (0 = saturated liquid, 1 = saturated vapor).

When calculating wet steam it is adequate to enter either the value given for  $t$  and  $p = -1$ , **or** the given value for  $p$  and  $t = -1$ , as well as the value for  $x$  between 0 and 1. If  $p$  and  $t$  and  $x$  are entered, the program considers  $p$  and  $t$  to represent the vapor-pressure curve.

Should this not be the case an error message is displayed ("OUT OF RANGE").

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

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

→ E.g.: The point of state to be calculated lies in the single-phase region. Therefore, enter the value -1 for  $x$ . The program displays the value -1 which you can confirm entering -2.

E.g., enter -2 (Note: Press the <(-)> key before the <2>).

- During the calculation, the following window is displayed:

```
TI IS WORKING
```

**Note:**

Should the following message be displayed the TI could not find all files.

```
ERR: ARCHIVED
1: Quit
2: Goto
```

Press <ENTER> and un-archive the FLUIDTI3, FLUIDTI4, FLUIDTI5, FLUIDTI6 files and the "E", "F", "G" and "H" list files. In order to do so, see the information under "Details: The TI-84 Plus flash memory" at the end of chapter 3.1 .

Then, start the example again.

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

```
STEAM REGION
H IN KJ/KG =
      3097.375274
```

→ In the example, the calculation results in 3097.375274.

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

**Note:** The value calculated for h has been saved as the variable "Θ" (<Θ> key).

Further on, that variable can be used independently of FluidTI.

With the next calculation, FluidTI overwrites the variable "Θ".

The values of v, s, t, and x would be saved as well after they have been calculated.

Press <ENTER> to return to the main menu.

Choose "7:END" with the cursor block and confirm with <ENTER>, or press <7> to finish the FluidTI program.

### 3.3 Uninstalling FluidTI

Do as follows:

1. Enter the memory menu pressing <2nd>, and <MEM> (above the <+> key). The following screen is displayed:

```

MEMO3%
1:About
2:Mem Mgmt/Del...
3:Clear Entries
4:ClrAllLists
5:Archive
6:UnArchive
7↓Reset...

```

2. Choose "2:Mem Mgmt/Del..." with the cursor block and press <ENTER>, or press <2>. The following window is displayed:

```

RAM FREE      8896
ARC FREE     36358
1:All...
2:Real...
3:Complex...
4>List...
5:Matrix...
6↓V-Vars...

```

3. Choose "7: Prgm..." and confirm with <ENTER>, or press <7> for the "Delete: Prgm" menu. The following window is displayed:

```

RAM FREE      8896
ARC FREE     36358
FLUIDTI      6513
FLUIDTI3     122
FLUIDTI4     1398
FLUIDTI5     2539
FLUIDTI6     145

```

4. Select the "FLUIDTI" file and press the <DEL> key.

```

Are You Sure%
1:No
2:Yes

```

Choose "2:YES" with the cursor block and confirm with <ENTER>, or press <2>.

5. Repeat the erasing procedure for the following files: "FLUIDTI3", "FLUIDTI4", "FLUIDTI5", and "FLUIDTI6".

6. Repeat the instructions of both paragraph 1 and 2. The following window is displayed:

```

RAM FREE      8896
ARC FREE     36358
1: All...
2: Real...
3: Complex...
4: List...
5: Matrix...
6: V-Vars...

```

7. Choose "4: List..." and confirm with <ENTER>, or press <4> for the "Delete: List" menu. The following window is displayed:

```

RAM FREE      8896
ARC FREE     36358
1: All...
2: Real...
3: Complex...
4: List...
5: Matrix...
6: V-Vars...

```

8. Search the "E" list and press the <DEL> key.

```

Are You Sure?
1: No
2: Yes

```

Choose "2: YES" with the cursor block and confirm with <ENTER>, or press <2>.

9. Repeat the erasing procedure for the following lists: "F", "G", and "H" .

10. Press <2nd>, and <QUIT> (above the <MODE> key) to return.

FluidTI has been uninstalled.

## 4. Program Documentation

### Saturation Pressure $p_s = f(t)$

**Name in FluidTI:** PS(T)

**Input**

T - temperature t in °C

**Output**

PS - saturation pressure  $p_s$  in MPa

**Range of validity**

From t = 0 °C to t = 373.946 °C .

**Response on faulty input values**

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

t < 0 °C or t > 373.946 °C

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

**Saturation Temperature  $t_s = f(p)$** 

**Name in FluidTI: TS(P)**

**Input**

**P** - pressure of p in MPa

**Output**

**TS** - saturation temperature  $t_s$  in °C

**Range of validity**

From  $p = 0.000611$  MPa to  $p = 22.064$  MPa .

**Response on faulty input values**

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

$p < 0.000611$  MPa or  $p > 22.064$  MPa

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

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

**Name in FluidTI: 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** - specific volume  $v$  in m<sup>3</sup>/kg

### Range of validity

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

Steam region : 0.000611 MPa...  $p = p_s(t)$  at 0 °C... 350 °C

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

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

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

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

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

Should the point of state to be calculated lie in the wet steam region the value to be entered for  $x$  ranges between 0 and 1 (0 = saturated liquid, 1 = saturated vapor).

When calculating wet steam it is adequate to enter either the value given for  $t$  and  $p = -1$ , or the value given for  $p$  and  $t = -1$ , as well as the value for  $x$  between 0 and 1. If  $p$  and  $t$  and  $x$  are entered the program considers  $p$  and  $t$  to represent the vapor-pressure curve. If this is not the case an error message is displayed.

Wet steam region:  $t = 0$  °C ... 350 °C

$p = 0.000611$  MPa ... 16.5292 MPa

### Response on faulty input values

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

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

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

( $0 \leq x \leq 1$ ) 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  $|t - t_s(p)| > 0.1$  K

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

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

**Name in FluidTI:** 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** - 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  $0 \text{ °C} \dots 350 \text{ °C}$

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

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

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

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

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

Should the point of state to be calculated lie in the wet steam region the value to be entered for  $x$  ranges between 0 and 1 (0 = saturated liquid, 1 = saturated vapor).

When calculating wet steam it is adequate to enter either the value given for  $t$  and  $p = -1$ , or the value given for  $p$  and  $t = -1$ , as well as the value for  $x$  between 0 and 1. If  $p$  and  $t$  and  $x$  are entered the program considers  $p$  and  $t$  to represent the vapor-pressure curve. If this is not the case an error message is displayed.

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

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

### Response on faulty input values

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

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

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

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

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

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

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

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

<b>Specific Entropy <math>s = f(p,t,x)</math></b>
---

**Name in FluidTI: 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** - specific entropy  $s$  in kJ/(kg K)

**Range of validity**

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

Steam region : 0.000611 MPa...  $p = p_s(t)$  at 0 °C... 350 °C

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

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

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

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

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

Should the point of state to be calculated lie in the wet steam region the value to be entered for  $x$  ranges between 0 and 1 (0 = saturated liquid, 1 = saturated vapor).

When calculating wet steam it is adequate to enter either the value given for  $t$  and  $p = -1$ , or the value given for  $p$  and  $t = -1$ , as well as the value for  $x$  between 0 and 1. If  $p$  and  $t$  and  $x$  are entered the program considers  $p$  and  $t$  to represent the vapor-pressure curve. If this is not the case an error message is displayed.

Wet steam region:  $t = 0$  °C ... 350 °C

$p = 0.000611$  MPa ... 16.5292 MPa

**Response on faulty input values**

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

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

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

( $0 \leq x \leq 1$ ) 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  $|t - t_s(p)| > 0.1$  K

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

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

**Name in FluidTI: T(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:  $p = 0.000611 \dots 16.5292$  MPa and  $h'(p) < h < h''(p)$

**Comment on the calculations for wet steam**

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

**Response on faulty input values**

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

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

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

Wet steam region: at values of  $p > 16.5292$  MPa or  $p < 0.000611$  MPa or  
at values of  $h < h'(p)$  or  $h > h''(p)$

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

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

**Name in FluidTI: T(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:  $p = 0.000611 \dots 16.5292$  MPa

**Comment on the calculations for wet steam**

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

**Response on faulty input values**

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

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

Steam region: at values of  $p$  and  $h$  beyond the IAPWS-IF97 region 2 (Figure 1), with  $s < 5.85$  kJ/(kg K)

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

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

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

**Name in FluidTI: X(P,H)**

**Input**

**P** - pressure p in MPa

**H** - specific enthalpy h in kJ/kg

**Output**

**X** - vapor fraction x in kg/kg

**Range of validity**

Liquid region: IAPWS-IF97 region 1 (Figure 1)

Steam region: IAPWS-IF97 region 2 (Figure 1)

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

**Comment on the calculations for wet steam**

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

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

**Response on faulty input values**

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

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

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

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

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

**Backward Function: Vapor fraction  $x = f(p,s)$** 

**Name in FluidTI:** X(P,S)

**Input**

**P** - pressure p in MPa

**S** - specific entropy s in kJ/(kg K)

**Output**

**X** - vapor fraction x in kg/kg

**Range of validity**

Liquid region: IAPWS-IF97 region 1 (Figure 1)

Steam region: IAPWS-IF97 region 2 (Figure 1)

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

**Comment on the calculations for wet steam**

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

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

**Response on faulty input values**

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

for  $p > 16.5292$  MPa or  $s < s'(p)$  or  $s > s''(p)$

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

$p < 0.000611$  MPa or  $p > 100$  MPa

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

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