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

**FluidTI  
LibIF97  
for  
TI-84 Plus**

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

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

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## 0. Package Contents

CD "FluidTI for TI-84 Plus" including 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 - User's Guide

User's Guide as printed copy (in case of shipment) .

# 1. Functions for the IAPWS-IF97

Functional Dependence	Function Name in FluidTl	Property or Function	Units
$p_s = f(t)$	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: region 1 and 2 of the IAPWS-IF97 including wet steam

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

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

0.000611 MPa...  $p_{23}(t) = p(s = 5.2 \text{ kJ/(kg K)})$  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 region (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 calculator shows an error.

Saturation line of the IAPWS-IF97:  $t = 0 \text{ °C} \dots 350 \text{ °C}$

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

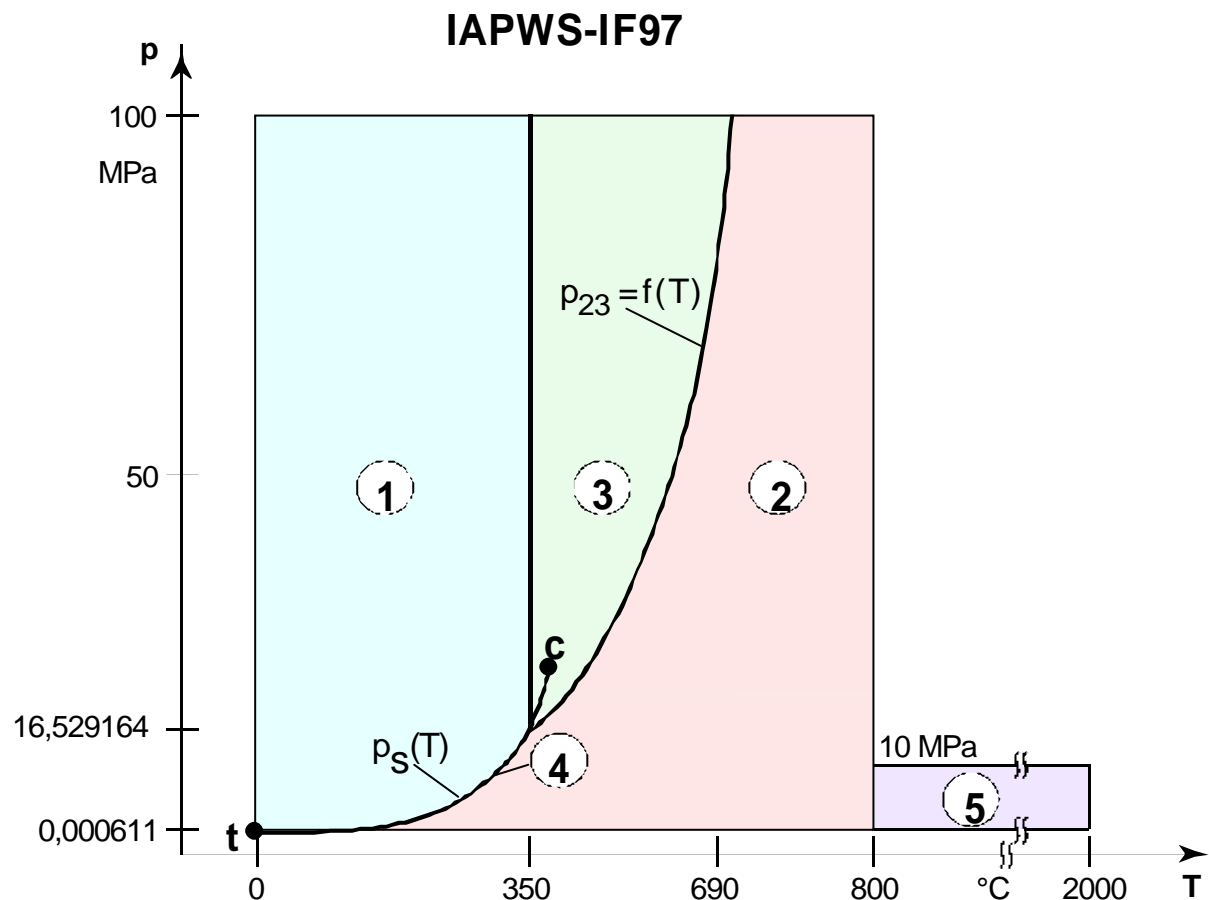
## Note !

If the input values lie outside the range of validity of the IAPWS-IF97 or they do not define a unique state point, the comment "OUT OF RANGE" will be shown.

## 2. Description of the IAPWS-IF97

The International Association for the Properties of Water and Steam IAPWS-IF97 issued the "IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam" in September 1997 [1,2,3]. It will be abbreviated as IAPWS-IF97. This new industrial standard has to be used in acceptance and guarantee calculations of facilities and plants working with water or steam worldwide. The IAPWS-IF97 Formulation replaces the former Industrial Formulation IFC-67 [12].

Figure 1 shows the entire range of validity of the equation set of the new Industrial Formulation IAPWS-IF97. It covers temperatures from 0 °C up to 800 °C for pressures from 0.000611 up to 100 MPa and temperatures up to 2000 °C for pressures up to 10 MPa.



**Figure 1:** Entire Range of Validity of the IAPWS-IF97

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

The student version of FluidTI cannot be used in the entire range of validity. Calculations are possible in regions 1 and 2 and wet steam region up to pressures of 16.529164 MPa (Figure 1).

The determination of the region and the call of the related equation of state is incorporated within the program.

### 3. Application of FluidTI for the calculation of water and steam

#### 3.1 Installation of FluidTI on TI-84 Plus

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

For that, 15 KB free memory (RAM) is required on the TI. If the memory is not available on the calculator programs can be archived in ARC-memory of the calculator without deleting them. The explanation is given under "Flash-memory TI-84 Plus:" at the end of Section 3.1 .

The link program and the USB-cable can be purchased in a store which sells TI calculators or ordered at Boettcher Datentechnik GmbH

<http://www.boettcher-datentechnik.de/> .

The following description refers to the link program

TI-Connect™,

which should be installed before (Instructions for the data transfer using other link programs can be taken from the belonging online helps or user's guides.) and to the system Windows®XP .

#### Installing FluidTI:

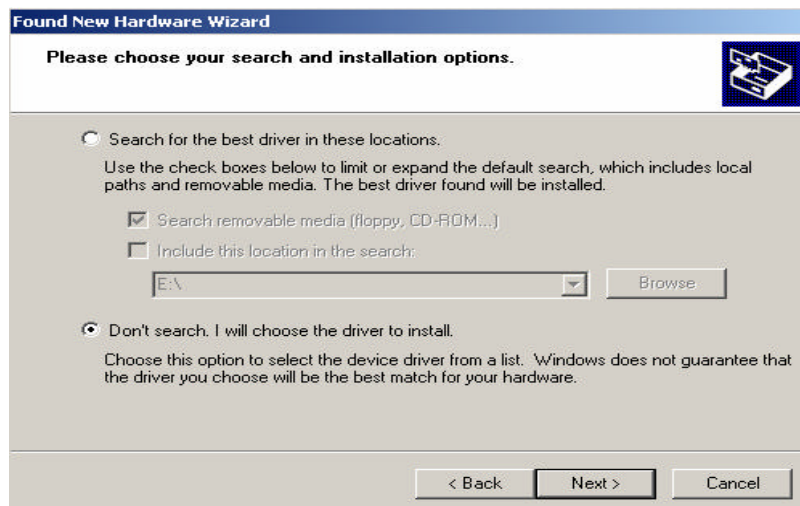
1. Connect the TI calculator with the PC as follows.  
Pluck the USB-cable in the TI calculator and in a free USB port of the PC.  
The TI-84 Plus turns on automatically by plucking in the USB cable.

At the first time the "Found New Hardware Wizard" opens automatically on the PC:



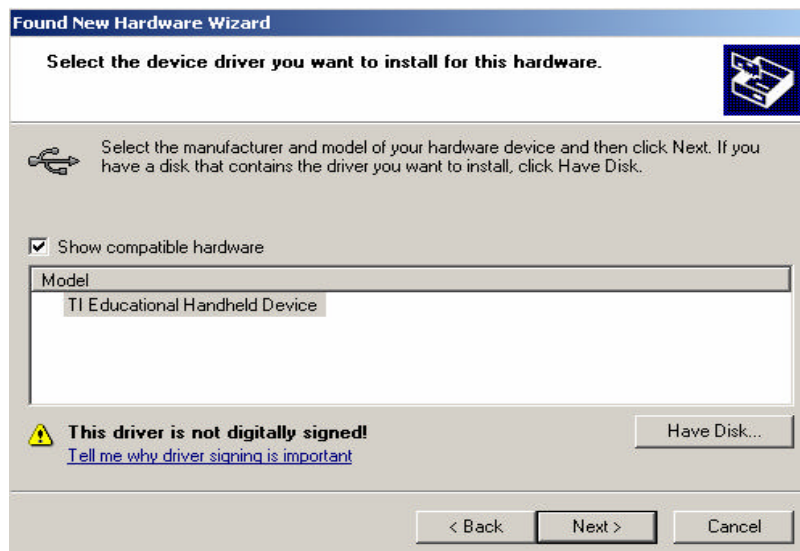
Mark the point "Install from a list or specific location" and click on "Next >" .

2. The following window appears:



Choose the point "Don't search. I will choose the driver to install." and confirm by clicking the button "Next >" .

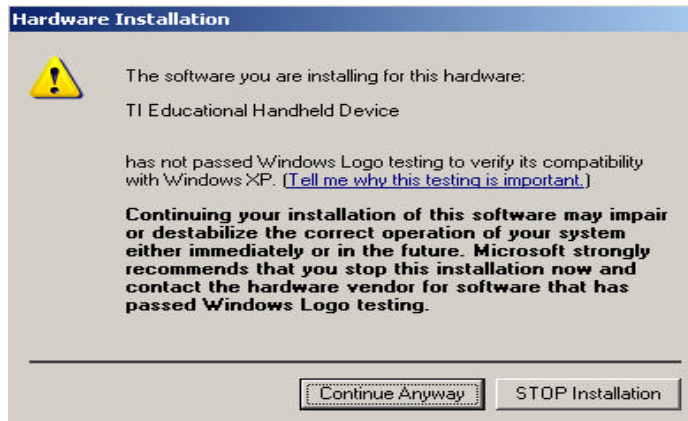
3. The next menu appears:



If "TI Education Handheld Device" appears in the window under "Model" then click on "Next >" .

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

4. The following window opens:



Click on "Continue Anyway" to continue the installation.

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



Click on the button "Finish" to close this window.

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

**Hint:** Check always that the calculator is on.

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

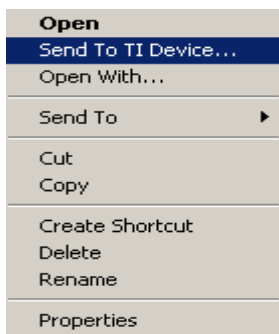
8. Click in the Windows task bar on "Start", then on "My Computer" and choose there the CD-Drive.

Open the file "TI-Files" on the CD by double clicking.

Mark all files by clicking with the left mouse button on the first file and press the "Shift"-key on the keyboard. While pressing "Shift", click with the left mouse button on the last file. Now, all files should be marked.

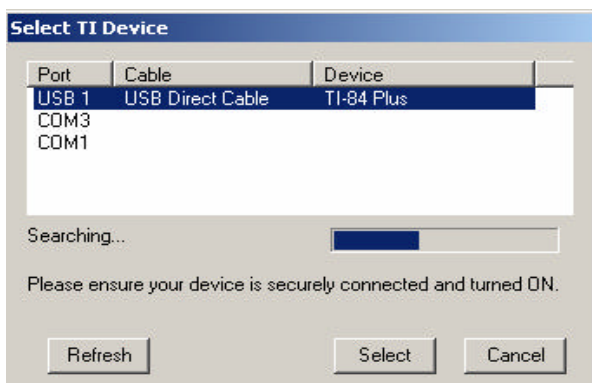


9. Click on the right mouse button while the cursor stands on a marked file. The following window appears:



Choose "Send to TI Device..." to send the marked files on the handheld.

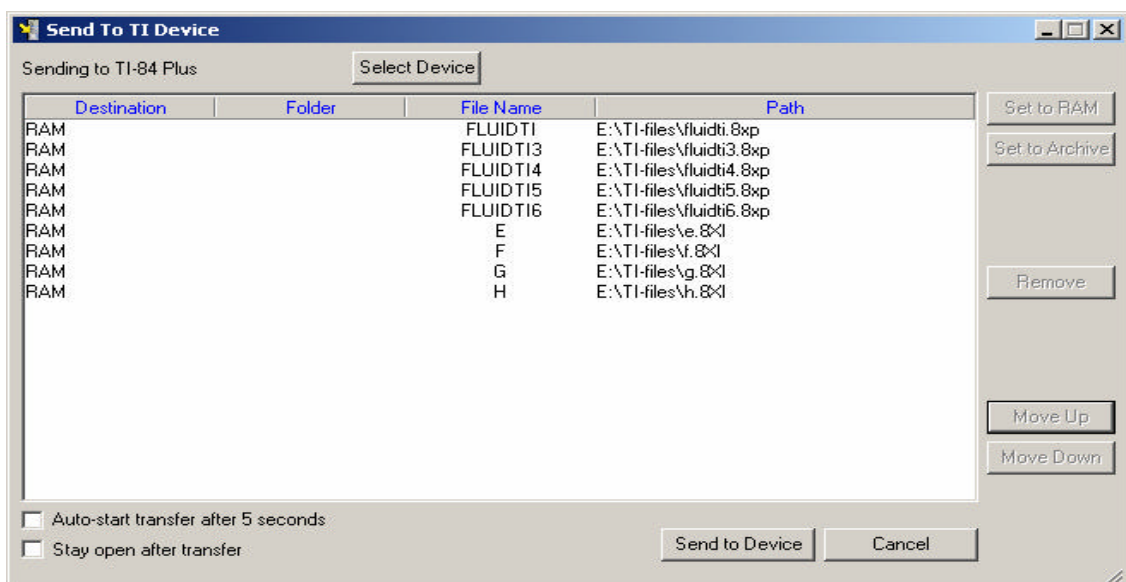
10. The following window can be shown, if not continue Paragraph 11:



Choose under "Port" the USB port connected with the calculator by clicking and click on the button "Select".

If the TI-84 Plus is not shown, turn the calculator on and try again by clicking on "Refresh".

11. The following window will be opened:

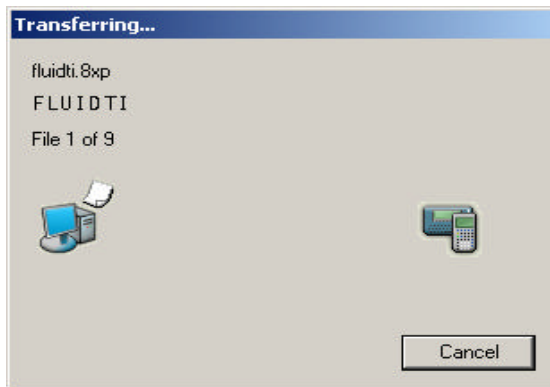


In the column under Destination should be written "RAM".

If not, click on the first file name in the list. The row will be marked. Now, choose for this file under Destination "RAM". Continue in the same way with the other files.

To start the transfer click on "Send to Device".

12. The following window is shown:



If this window is closed without displaying an error the copying was successful.

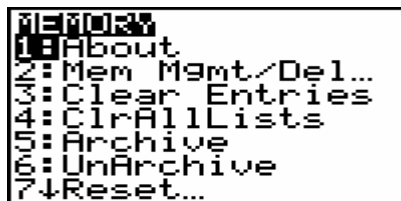
If the files were not copied, there are the following possibilities of errors:

- The USB interface could not choose for the transfer.  
Switch on the TI-84 Plus and try it again.
- The plugs were not correctly put in.

### Flash-memory at TI-84 Plus:

The following steps show how to archive programs to reach more RAM memory.

1. Enter the memory menu by pressing <2nd> and <MEM> (upper the <+> - key). The following screen will be shown:

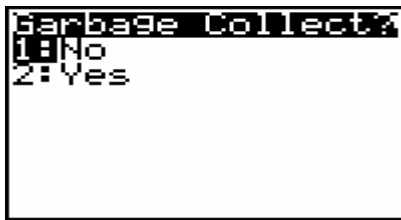


2. Choose "2:Mem Mgmt/Del..." with the cursor-block and press <ENTER> or press key <2>. The following window appears:



3. If the number behind "RAM FREE" is higher than 15000, there are enough RAM-memory for the installation of FluidTI. Press <2nd> and <QUIT> (upper the <MODE> - key) to return. Otherwise read the next paragraphs:
4. Choose "7: Prgm..." and confirm with <ENTER> or press key <7>.

5. Now all programs are listed with their memory capacity in Byte (on the right). Behind "RAM FREE" will be shown the size of free RAM-memory. Behind "ARC FREE" the free ARCHIVES-memory. Place the cursor with the cursor-block in front of a program and press <ENTER> to archive it. Now a star appears in front of the program. (If instead the window "Garbage Collect?" open, read at first paragraph 7.) The star symbolizes the archived condition. The figure behind "RAM FREE" rises about the size of the archived program. Repeat this up to 15 KB free RAM-memory.
6. To un-archive a program place the cursor again in front of it and press <ENTER>. The star disappears and the program is back in the RAM-memory. After archive and un-archive some programs, the following window appears:



7. Choose "2:YES" with the cursor-block and confirm with <ENTER> or press key <2>. This lasts half a minute. The pocket calculator delete some unnecessary data in the archives.

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

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

To do this, the following steps must be completed:

- Press on the <PRGM> - key to open the program menu.
- Start the program by choosing "FLUIDTI" with the cursor block and press <ENTER> to confirm. "prgmFLUIDTI" will be shown on your calculator screen.

A screenshot of a TI-84 Plus calculator screen. The text 'PrgmFLUIDTI' is displayed in the top line of the screen.

Press <ENTER> again.

- The following screen will be shown:

A screenshot of a TI-84 Plus calculator screen. The text 'FLUIDTI' is at the top, followed by 'STEAMTABLES', 'IAPWS-IF97', 'VERSION FOR', and 'STUDENTS' on separate lines. A cursor is visible on the right side of the screen.

**Hint:**

In case the following message arises

A screenshot of a TI-84 Plus calculator screen. The text 'ERR:ARCHIVED' is at the top, followed by '1:Quit' and '2:Goto' on separate lines.

TI could not find the program FLUIDTI. Press <ENTER> and un-archive the file FLUIDTI. For this, follow the description "Flash-memory TI-84 Plus:" at the end of paragraph 3.1 .

Then, start the example again.

- Press <ENTER> for the function menu of FluidTI:

A screenshot of a TI-84 Plus calculator screen. The text 'IAPWS-IF97' is at the top. Below it, a list of functions is shown: '1:PSCT', '2:TS(P)', '3:V(P,T,X)', '4:H(P,T,X)', '5:S(P,T,X)', '6:CONTINUE', and '7:END'. A cursor is visible on the right side of the screen.

- Move with the cursor to "6:CONTINUE" and then press <ENTER> or press the key <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

```

Move with the cursor to "7:MENU BEGIN" and then press <ENTER> or press the key <7> to return to the first part of the menu.

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

The following input window for pressure p in MPa appears:

```

P IN MPa =      .1
-2->TAKE THIS
P=■

```

Pay attention to the range of validity of the IAPWS-IF97:

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

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

**Note:** The current value shown in the second line can be taken over by entering of -2.

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

```

T IN °C =      100
-2->TAKE THIS
T=■

```

Pay attention to the range of validity of the IAPWS-IF97:

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

→ 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 shown:

```

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

```

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

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

In case, the point to be calculated is in the wet steam region, 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, appears "OUT OF RANGE".

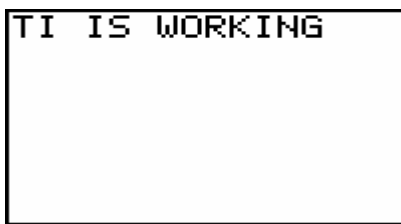
Wet steam region:  $t = 0\text{ °C} \dots 350\text{ °C}$

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

→ e.g.: The point which should be calculated is situated in the single phase region. Therefore, enter the value -1 for  $x$ . Here the program show -1 and you can take over it by entering -2.

For example enter -2 (Attention: press the key <-> for the sign).

- During the calculation, the following window will be shown:



#### Hint:

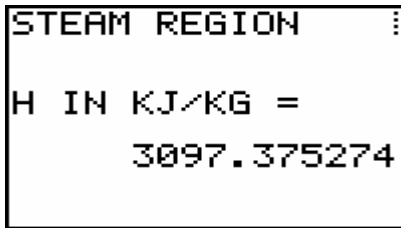
In case the following message arises



TI could not find all files. Press <ENTER> and un-archive the files FLUIDTI3, FLUIDTI4, FLUIDTI5, FLUIDTI6 and the list files "E", "F", "G" and "H". For this, follow the description under "Flash-memory TI-84 Plus:" at the end of paragraph 3.1.

Then start the example again.

- After calculation, the result for  $h$  in kJ/kg is shown at the display:



```

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

→ e.g.: In the example the value 3097.375274 should arise.

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

**Note:** The calculated value for  $h$  has been stored into the variable "T" (key <T>).

Afterwards, this variable can be used independently of FluidTI.

In the next calculation, FluidTI will overwrite the variable "T".

The values for  $v$ ,  $s$ ,  $t$  and  $x$  also would be stored after their calculation.

Now, press <ENTER> to return to the main menu.

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

### 3.4 Removing FluidTI

The following steps must be completed:

1. Enter the memory menu by pressing <2nd> and <MEM> (upper the <+> - key). The following screen will be shown:

```

MEMO2%
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 key <2>. The following window appears:

```

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

```

3. Choose "7: Prgm..." and confirm with <ENTER> or press key <7> for the program delete menu. The following window will be shown:

```

RAM FREE    8896
ARC FREE    36358
▶ FLUIDTI1   6513
  FLUIDTI3    122
  FLUIDTI4    1398
  FLUIDTI5    2539
  FLUIDTI6     145

```

4. Search the file "FLUIDTI". Then press the key <DEL>.

```

Are You Sure%
1:No
2:Yes

```

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

5. Repeat the deleting process for the following files: "FLUIDTI3", "FLUIDTI4", "FLUIDTI5" and "FLUIDTI6".



6. Repeat the steps under paragraph 1 and paragraph 2. The following window appears:

```

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 key <4> for the list delete menu. The following window will be shown:

```

RAM FREE      8896
ARC FREE     36358
E             849
F             1002
G             849
H             903

```

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

```

Are You Sure?
1: No
2: Yes

```

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

9. Repeat the deleting process for the following lists: "F", "G" and "H" .
10. Press <2nd> and <QUIT> (upper the <MODE> - key) to return.
- FluidTI has been removed.

## 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  $t = 0\text{ °C}$  to  $t = 373.946\text{ °C}$ .

**Reaction for wrong input**

Error message "Out of Range" for input values:

$t < 0\text{ °C}$  or  $t > 373.946\text{ °C}$

**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 .

**Reaction for wrong input**

Error message "Out of Range" for 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  $\text{m}^3/\text{kg}$

**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  $0 \text{ °C} \dots 350 \text{ °C}$

$0.000611 \text{ MPa} \dots p_{23}(t) \approx p(s = 5.2 \text{ kJ}/(\text{kg K}))$  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 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 region (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 calculator shows an error.

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

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

**Reaction for wrong input**

Error message "Out of Range" for input values:

Single phase region: The entered parameters are outside of 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 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 :  $p = p_s(t) \dots 100 \text{ MPa}$  for  $0 \text{ °C} \dots 350 \text{ °C}$

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

$0.000611 \text{ MPa} \dots p_{23}(t) \approx p(s = 5.2 \text{ kJ/(kg K)})$  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**

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 region (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 calculator shows an error.

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

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

**Reaction for wrong input**

Error message "Out of Range" for input values:

Single phase region: The entered parameters are outside of 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 FluidTl:  $S(P, T, X)$**

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

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

$0.000611 \text{ MPa} \dots p_{23}(t) \approx p(s = 5.2 \text{ kJ/(kg K)})$  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**

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 region (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 calculator shows an error.

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

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

**Reaction for wrong input**

Error message "Out of Range" for input values:

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

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

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

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

**Name in 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 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 or  
at values of  $h < h'(p)$  or  $h > h''(p)$

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

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

**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 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), with  $s < 5.85$  kJ/(kg K)

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 FluidTl:** 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 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 program calculate the value of  $x$ . Otherwise the calculator shows  $x = -1$ .

**Reaction for wrong input**

Result  $x = -1$  for input values:

In case the condition point lies in the one phase area (liquid or steam):

for  $p > 16.5292$  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]

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

**Name in FluidTl:** 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 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 program calculate the value of  $x$ . Otherwise the calculator shows  $x = -1$ .

**Reaction for wrong input**

Result  $x = -1$  for input values:

In case the condition point lies in the one phase area (liquid or steam):

for  $p > 16.5292$  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]

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