Water & Steam Properties

Introduction

Water-SteamProperties.xla is an Add-In for MS Excel which provides a set of functions for calculating thermodynamic properties of water and steam using the industrial standard IAPWS-IF97. Also Water-SteamProperties.xls is a stand alone program that users can use it directly to find desired thermodynamics properties, without any need to insert functions manually.

In 1997, the International Association for the Properties of Water and Steam (IAPWS) adopted a new formulation for the thermodynamic properties of water and steam for industrial use. This new formulation, called IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam (IAPWS-IF97), replaces the previous industrial formulation, IFC-67, that had formed the basis for power-plant calculation and other applications in energy engineering since the late 1960's. IAPWS-IF97 improves significantly both accuracy and speed of the calculation of the thermodynamic properties compared with IFC-67.

The presented application provides ease access to thermodynamic properties of water and steam. Extreme accuracy, speed and easy manipulation of results should make engineering calculations much more enjoyable. A summarized table of available functions is provided at the end of document.

Getting Started

The functions are provided as an Add-In file (Water-SteamProperties.xla) for MS Excel. After downloading the file which contains "Water-SteamProperties.xla" you can load it in Excel every time you need it by going to "Tools → Add-ins" or by simply double clicking on "Water-SteamProperties.xla" in Explorer. The water property functions are then available just like other built-in functions in Excel. In the function wizard list, they can be found under "User Defined". See also the documentation for MS Excel for more information about add-in files.

If you want to use Water-SteamProperties.xls file, just open it like other excel files and use it as a tool for thermodynamics properties calculation.

Regions

Figure 1 shows the five regions into which the entire range of validity of IAPWS-IF97 is divided:
For more detailed information about the boundaries of the regions, and equations involved refer to "Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam" presented by The International Association for the Properties of Water and Steam.

Please notice that in the current version of program, the region 5 is excluded, because in normal engineering problems, these conditions happen rarely.

**Range of validity**

The entire set of equations of IAPWS-IF97, used by the application for calculation of thermodynamic properties, is defined by the following temperature and pressure range:

\[
0 \leq T \leq 800 \, ^\circ\text{C} \quad p \leq 1000 \, \text{bar}
\]

**Input variables**

To calculate properties, Water-SteamProperties.xla allows up to 11 different combinations of input variables in SI units:

1. \(f\) (pressure, temperature)
2. \(f\) (pressure, enthalpy)
3. \( f \) (pressure, entropy)
4. \( f \) (pressure, specific volume)
5. \( f \) (pressure, internal energy)
6. \( f \) (temperature, quality)
7. \( f \) (pressure, quality)

Range of validity for listed functions:
- Functions 1 is valid in all first four (1 to 4) regions defined by IAPWS-IF97.
- Functions 2-5 are valid in regions 1, 2 and 4 defined by IAPWS-IF97.
- Functions 6 and 7 are valid in region 4 (saturation region) only.

❖ **Calculable properties in SI units**

The following thermodynamic properties can be calculated with Water-SteamProperties.xla:

1. Pressure
2. Temperature
3. Specific Volume
4. Specific enthalpy
5. Specific entropy
6. Specific internal energy

❖ **Reference of available functions**

1. **Specific volume in single-phase state**
   a) Usage: \( v_{tp}(T, P) \)
   b) Argument(s): 
   \( T \) temperature in °C
   \( P \) pressure in bar
   c) Unit: specific volume in \( \text{m}^3/\text{kg} \)
   d) Range of validity: 0 °C < \( T < 800 \) °C and 0 < \( p < 1000 \) bar
   e) Error: \( v_{tp} = -1 \), temperature and/or pressure outside range
   f) Example: specific volume of water at 1 bar and 20 °C
   formula in worksheet cell: \( =v_{tp}(20, 1) \)

2. **Specific internal energy in single-phase state**
   a) Usage: \( u_{tp}(T, P) \)
   b) Argument(s): 
   \( T \) temperature in °C
3. Specific enthalpy in single-phase state

a) Usage:
   \( h_{tp}(T, P) \)

b) Argument(s):
   - \( T \) temperature in °C
   - \( P \) pressure in bar

c) Unit:
   specific enthalpy in kJ/kg

d) Range of validity:
   \( 0 \, ^\circ\text{C} < T < 800 \, ^\circ\text{C} \) and \( 0 < p < 1000 \) bar

e) Error:
   \( h_{tp} = -1 \), temperature and/or pressure outside range

f) Example:
   specific enthalpy of water at 10 bar and 130°C
   formula in worksheet cell: \( = h_{tp}(130, 10) \)

4. Specific entropy in single-phase state

a) Usage:
   \( s_{tp}(T, P) \)

b) Argument(s):
   - \( T \) temperature in °C
   - \( P \) pressure in bar

c) Unit:
   specific entropy in kJ/kg

d) Range of validity:
   \( 0 \, ^\circ\text{C} < T < 800 \, ^\circ\text{C} \) and \( 0 < p < 1000 \) bar

e) Error:
   \( s_{tp} = -1 \), temperature and/or pressure outside range

f) Example:
   specific entropy of water at 200 bar and 300°C
   formula in worksheet cell: \( = s_{tp}(300, 200) \)

5. Saturation temperature as a function of pressure

a) Usage:
   \( t_{sat}(P) \)

b) Argument(s):
   - \( P \) pressure in bar

c) Unit:
   saturation temperature in °C

d) Range of validity:
   \( 0.00611657 \text{ bar} < p < 220.64 \text{ bar} \)

e) Error:
   \( t_{\text{SatW}} = -1 \), pressure outside range

f) Example:
   saturation temperature of water at 1 bar in °C
6. Saturation pressure as a function of temperature

a) Usage: \( p\_sat(T) \)
b) Argument(s): \( T \) temperature in °C
c) Unit: saturation pressure in bar
d) Range of validity: \( 0 \degree C < T < 373.946 \degree C \)
e) Error: \( p\_sat = -1 \), temperature outside range
f) Example: saturation pressure of water at 100 °C

7. Specific volume in saturation state

a) Usage: \( v\_tx(T, x) \), specific volume of saturated water and steam as a function of temperature and quality
\( v\_px(P, x) \), specific volume of saturated water and steam as a function of pressure and quality
b) Argument(s): \( T \) temperature in °C or \( P \) pressure in bar, \( x \) in decimal/percent%
c) Unit: specific volume in m\(^3\)/kg
d) Range of validity: \( 0 \degree C < T < 373.946 \degree C \) or \( 0.00611657 \text{ bar} < P < 220.64 \text{ bar} \) and \( 0\% < x < 100\% \)
e) Error: \( v\_?x = -1 \), temperature or pressure outside range
f) Example: specific volume of saturated water at 1 bar

8. Specific internal energy in saturation state

a) Usage: \( u\_tx(T, x) \), specific volume of saturated water and steam as a function of temperature and quality
\( u\_px(P, x) \), specific volume of saturated water and steam as a function of pressure and quality
b) Argument(s): \( T \) temperature in °C or \( P \) pressure in bar, \( x \) in decimal/percent%
c) Unit: specific internal energy in kJ/kg
d) Range of validity: \( 0 \degree C < T < 373.946 \degree C \) or \( 0.00611657 \text{ bar} < P < 220.64 \text{ bar} \) and \( 0\% < x < 100\% \)
e) Error: \( u\_?x = -1 \), temperature or pressure outside range
f) Example: specific internal energy of saturated steam at 100 °C

9. Specific enthalpy in saturation state

a) Usage: \( h\_tx(T, x) \), specific enthalpy of saturated water and steam as a function of temperature and quality
\( h\_px(P, x) \), specific enthalpy of saturated water and steam as a function of pressure and quality
pressure and quality

b) Argument(s): T temperature in °C or P pressure in bar, x in decimal/percent%
c) Unit: specific enthalpy in kJ/kg
d) Range of validity: 0 °C < T < 373.946 °C or 0.00611657 bar < p < 220.64 bar and 0% < x < 100%
e) Error: h_?x = -1, temperature or pressure outside range
f) Example: specific enthalpy of saturated steam at 100 °C
   formula in worksheet cell: =h_tx(100, 1)

10. Specific entropy in saturation state

a) Usage: s_tx(T, x), specific entropy of saturated water and steam as a function of temperature and quality
   s_px(P, x), specific entropy of saturated water and steam as a function of pressure and quality
b) Argument(s): T temperature in °C or P pressure in bar, x in decimal/percent%
c) Unit: specific entropy in kJ/kg/K
d) Range of validity: 0 °C < T < 373.946 °C or 0.00611657 bar < p < 220.64 bar and 0% < x < 100%
e) Error: s_?x = -1, temperature or pressure outside range
f) Example: specific enthalpy of saturated steam at 100 °C
   formula in worksheet cell: =s_px(100, 0)

11. Temperature as a function of pressure and specific volume

a) Usage: t_pv(P, v)
b) Argument(s): P pressure in bar and v in m³/kg
c) Unit: temperature in °C
d) Range of validity: 0.00611657 bar < p < 220.64 bar
e) Error: t_pv = -1, pressure or specific volume outside range
f) Example: temperature of water at 100 bar and v =0.001 m³/kg
   formula in worksheet cell: =t_pv(100, 0.001)

12. Temperature as a function of pressure and specific energy

a) Usage: t_pu(P, u)
b) Argument(s): P pressure in bar and u in kJ/kg
c) Unit: temperature in °C
d) Range of validity: 0.00611657 bar < p < 220.64 bar
e) Error: t_pu = -1, pressure or specific energy outside range
f) Example: temperature of water at 100 bar and \( u = 1000 \) kJ/kg

formula in worksheet cell: \( =t_{pu}(100, 1000) \)

13. Temperature as a function of pressure and specific enthalpy

a) Usage: \( t_{ph}(P, h) \)

b) Argument(s): \( P \) pressure in bar and \( h \) enthalpy in kJ/kg

c) Unit: temperature in °C

d) Range of validity: \( 0.00611657 \text{ bar} < p < 220.64 \text{ bar} \)

e) Error: \( t_{ph} = -1 \), pressure or specific enthalpy outside range

f) Example: temperature of water at 100 bar and \( h = 2600 \) kJ/kg

formula in worksheet cell: \( =t_{ph}(100, 2600) \)

14. Temperature as a function of pressure and specific entropy

a) Usage: \( t_{ps}(P, s) \)

b) Argument(s): \( P \) pressure in bar and \( s \) entropy in kJ/kg/K

c) Unit: temperature in °C

d) Range of validity: \( 0.00611657 \text{ bar} < p < 220.64 \text{ bar} \)

e) Error: \( t_{ps} = -1 \), pressure or specific entropy outside range

f) Example: temperature of water at 50 bar and \( s = 3 \) kJ/kg/K

formula in worksheet cell: \( =t_{ps}(50, 3) \)

💡 Calculation procedure with Water-SteamProperties.xla

In order to calculate properties directly by inserting the formula, act normally as other internal functions in Excel.

💡 Calculation procedure with Water-SteamProperties.xls

In order to calculate properties, follow these steps:

1. Select one of the 2 different input variables in the first select box.
2. Enter data for the first parameter in the text box.
3. Click on "Enter"
4. Select one of the 6 different input variables in the second select box.
5. Enter data for the second parameter in the next text box.
6. Click on "Enter"
7. Press Calculate it... button to perform calculation.
<table>
<thead>
<tr>
<th>Name in Excel</th>
<th>Arguments</th>
<th>Function Output</th>
<th>Range of validity</th>
<th>Error message</th>
</tr>
</thead>
<tbody>
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<td>v: specific volume in m^3/kg</td>
<td>0 °C &lt; T ≤ 1000 °C, 0 &lt; P &lt; 1000 bar Regions 1, 2 and 3 in Fig.1</td>
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**These functions work base on iteration; it's possible to receive Error Message even when your inputs are within defined limits. This error means that your inputs can not be matched in the regions 1, 2 and 4.**